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Original paper

The Dynamics of the Mollusks *Mytilaster lineatus* Settlement in the Black Sea Waters with Different Degrees of Petroleum Pollution

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Abstract

The paper estimates the dynamics of the settlement of mytilasters in the coastal water area with different degrees of petroleum pollution using the example of Sevastopol Bay (high level of anthropogenic load) and Laspi Bay (conditionally clean water area). To assess the marine environment quality at the sites of mytilaster fouling in the mentioned bays, data on the petroleum hydrocarbons content in the water was analysed (2012, 2015, 2018). The study material was samples of *Mytilaster lineatus* mollusks and bottom sediments taken in Sevastopol Bay from 2012 to 2018 at depths from 7 to 17 m during three sanitary and biological surveys. The abundance of mytilasters on various natural and artificial substrates of Sevastopol Bay in 2012, 2015 and 2018 under conditions of chronic oil pollution was analysed. It was revealed that the abundance of mytilasters on solid substrates was primarily influenced not by pollution of the marine environment but by water temperature and surf-wave phenomena. The values of the functional abundance index show that under chronic petroleum pollution, mytilasters, inhabiting artificial substrates of Sevastopol Bay, make a more significant contribution to transformation of matter and energy. At the same time, the energy significance of the studied mollusks in the soils of Sevastopol Bay is considerably lower than that in the conditionally clean water area (Laspi Bay). An analysis of average abundance and biomass of mollusks for 2012, 2015 and 2018 showed that the number of mytilasters in the marine soils of Sevastopol Bay increased. It was established that the quality of life of the community was influenced by the physical and chemical parameters of bottom sediments, which either accelerate or slow down the oxidation processes, thereby changing the oxygen level in the bottom sediments. According to the correlation analysis results, there is a direct relationship between the abundance, biomass of mollusks and concentrations of chloroform-extractable substances, petroleum hydrocarbons and redox potential. It was revealed that in the soils of Laspi Bay, the quantitative indicators of mytilasters were four times higher than in Sevastopol Bay.

Keywords: coastal waters, Mytilaster, artificial substrates, natural substrates, petroleum hydrocarbons, Black Sea

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Динамика поселения моллюсков *Mytilaster lineatus* в черноморской акватории с различной степенью нефтяного загрязнения

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Аннотация

Оценена динамика поселения митилястеров в прибрежной акватории с различной степенью нефтяного загрязнения на примере бухт Севастопольской (высокий уровень антропогенной нагрузки) и Ласпи (условно чистая акватория). Для оценки качества морской среды в местах отбора обрастаний митилястеров в бухтах Севастопольской и Ласпи проанализировали данные о содержании нефтяных углеводородов в воде (2012, 2015 и 2018 гг.). Материалом для исследования послужили пробы моллюсков *Mytilaster lineatus* и донных осадков, отобранные в Севастопольской бухте с 2012 по 2018 г. с глубин от 7 до 17 м в рамках трех санитарно-биологических съемок. Проанализировано обилие митилястеров на различных естественных и искусственных субстратах б. Севастопольской в 2012, 2015 и 2018 гг. в условиях хронического нефтяного загрязнения. Выявлено, что на обилие митилястеров на твердых субстратах в первую очередь влияет не загрязнение морской среды, а температура воды и прибойно-волновые явления. Значения индекса функционального обилия показывают, что в условиях хронического нефтяного загрязнения митилястеры, обитающие на искусственных субстратах б. Севастопольской, вносят более значимый вклад в преобразование вещества и энергии. При этом энергетическая значимость исследуемых моллюсков в грунтах б. Севастопольской значительно ниже, чем в условно чистой акватории (б. Ласпи). Анализ средних значений численности и биомассы моллюсков в 2012, 2015 и 2018 гг. показал, что обилие митилястеров в морских грунтах б. Севастопольской увеличилось. Установлено, что на качество жизни сообщества оказывают влияние физико-химические показатели донных осадков, которые либо ускоряют, либо замедляют процессы окисления, изменяя тем самым содержание кислорода в донных отложениях. По результатам корреляционного анализа наблюдается прямая взаимосвязь между численностью, биомассой моллюсков и концентрациями хлороформ-экстрагируемых веществ, нефтяных углеводородов и окислительно-восстановительным потенциалом. Выявлено, что в грунтах б. Ласпи количественные показатели митилястеров в четыре раза выше, чем в б. Севастопольской.

Ключевые слова: прибрежная акватория, митилястеры, искусственные субстраты, естественные субстраты, нефтяные углеводороды, Черное море

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Introduction

Mytilaster (*Mytilaster lineatus* (Gmelin, 1791)) is a mass and widespread Black Sea species of coastal communities, forming settlements on various natural and artificial substrates. These mollusks contribute significantly to the filtration activity of mytilid settlements [1, 2], acting as a powerful natural biofilter [3]. Mytilasters are known to filter water 18 h/day [1)], removing bacterial suspension from it [4]. They are able to reduce the level of organic pollution of the water area significantly, including the concentration of petroleum products [5].

The mollusks under study are distributed quite widely and can be found on the Atlantic coast of southern Europe as well as in all seas of the Mediterranean basin [3]. They have been introduced to the Caspian Sea, where they are widely distributed [2)]. Mytilasters dominate in most areas of the Sea of Azov [6], forming settlements in muds under conditions of hypoxia and elevated temperatures as well as at increased content of petroleum products in bottom sediments [7].

Mytilasters are found in the Black Sea from the water edge to depths of 50–70 m. However, they form permanent breeding settlements only at shallow depths (3–8 m), mainly in the coastal zone. There, mytilasters are found on rocks among cystosira thickets (natural substrate) and on hydraulic structures (artificial substrate) [8, 9]. Mollusks also form mud communities, but less abundant than on hard substrates [3]. An increase in the abundance and biomass of Mytilaster species is observed in sheltered parts of bays where the surf action is weakened [10].

In recent years, the mytilid fouling of the Crimean coast has undergone a significant transformation [11, 12]. Mussels become smaller and less abundant, and mytilasters inhabit free spaces on both natural and artificial substrates [9]. The dominance of the studied mollusk species was previously observed on hydraulic structures of various coastal waters of Sevastopol [13]. In 2008–2009, the bivalve

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[1)] Mironov, G.N., 1948. [Filtration and Nutrition of Black Sea Mussels]. *Trudy Sevastopolskoy Biologicheskoy Stantsii*, 6, pp. 338–352 (in Russian).

[2)] Scarlato, O.A. and Starobogatov, Ya.I., 1972. Class Bivalvia. In: V. A. Vodyanitskiy, ed., 1972. [*Field Guide for the Black Sea and the Sea of Azov Fauna*]. Kiev: Naukova Dumka. Vol. 3, pp. 178–249 (in Russian).

Mytilaster lineatus was also clearly dominant among other macrozoobenthos species in terms of abundance, biomass, and occurrence in all seasons and at all depths on the rocky soil of Karantinnaya Bay (Sevastopol) [14].

From 2009 to 2014, mytilasters were recorded on natural hard substrates in the waters of such reserves of the Crimean Peninsula as Cape Martyan Reserve, Karadag, Opuk, Kazantip Nature Reserves as well as in the water area of the Tarkhankut National Nature Park [15]. At the same time, this mollusk found in the above five areas has the highest abundance and biomass.

Petroleum and petroleum products are main permanent pollutants of the Black Sea coastal waters, including the Sevastopol water area. Sevastopol Bay is most polluted by the parameter under consideration [10]. It belongs to the water areas of active economic use, the main part of its coastline is occupied by berths and related infrastructure with a total length of 11 km. At the same time, the harbour is home to a significant number of warships and civilian vessels, which are one of the main sources of pollution of the bay with petroleum products. In addition, storm water and sewage runoff are discharged into the water area, and due to impeded water exchange, pollutants accumulate in the bay bottom sediments, worsening its ecological condition.

Mytilasters occur in Sevastopol Bay on all the above described substrates [1, 9, 16] and play an important role in the process of marine environment self-purification from petroleum and petroleum products. This was a prerequisite for studying the dynamics of mytilaster settlements in this polluted area. Laspi Bay was chosen as a conditionally clean water area, the coastal zone of which is characterised as relatively safe in terms of certain physical and chemical and microbiological parameters of seawater [17].

The aim of the work is to analyse the dynamics of settlement of mytilasters on natural and artificial substrates in the coastal waters with different degrees of petroleum pollution (on the example of Sevastopol and Laspi bays) according to the literature data and data of monitoring surveys (2012, 2015, 2018).

Within the framework of the set aim, the following tasks were formulated:

1) to analyse the abundance of mytilasters on various natural and artificial substrates of Sevastopol Bay for 2012–2018 in the conditions of chronic petroleum pollution of the studied water area according to the literature data;

2) to determine the abundance and biomass of *Mytilaster lineatus* mollusks in the Sevastopol Bay muds based on the data of monitoring surveys in 2012, 2015 and 2018, taking into account the pollution of bottom sediments with organic substances, including petroleum hydrocarbons;

3) to determine the contribution of mytilasters to the processes of matter and energy transformation in bottom communities in water areas subjected to chronic petroleum pollution and in conditionally clean water areas;

4) to compare mollusk settlements in conditionally clean and polluted water areas.

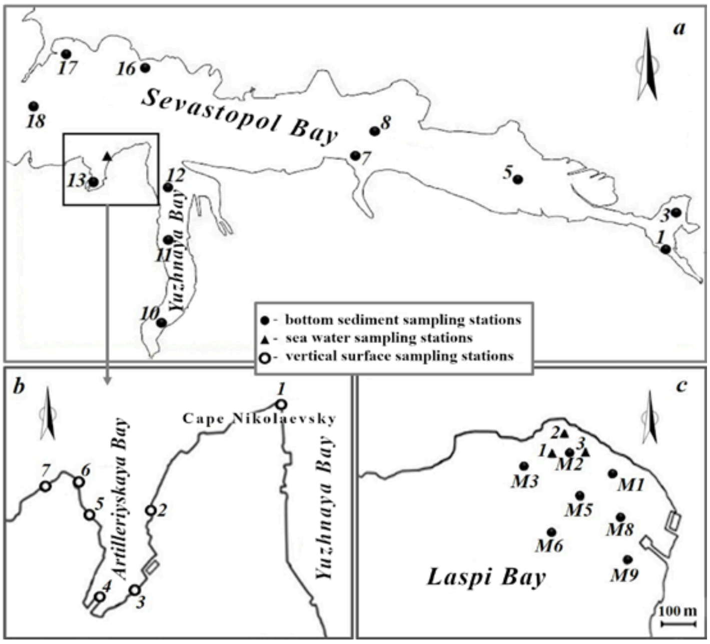
Material and methods

To assess the quality of the marine environment at the sites of sampling of mytilaster fouling in Sevastopol and Laspi bays, literature data on the content of petroleum hydrocarbons (PHCs) in water were analysed [10, 18–20] (Figure, *a*, *c*).

The indicators of abundance and biomass of mytilasters on artificial substrates in Sevastopol Bay were analysed according to literature data [9, 10, 13, 21]. The scheme of location of mollusk sampling stations from the mooring walls is presented in Figure, *b*.

Samples of *Mytilaster lineatus* mollusks and bottom sediments were taken in Sevastopol Bay from 2012 to 2018 at depths ranging from 7 to 17 m (Figure, *a*) during three sanitary and biological surveys conducted systematically by the Laboratory of Chemoecology (formerly the Department of Marine Sanitary Hydrobiology) of Institute of Biology of the Southern Seas.

To determine hydrobionts, bottom sediments were sampled with a Petersen dredge (0.038 m^2 capture area) in two repetitions. The bottom sediment was washed through a sieve (1 mm mesh diameter), fixed with ethanol (96%) and then viewed under binoculars. Next, the abundance and crude weight of the organisms



Location of sampling stations for bottom sediment in Sevastopol Bay (*a*), mytilasters from hydraulic structures in Sevastopol Bay (*b*) (literature data [12]) in 2012, 2015, 2018 and seawater and bottom sediment in Laspi Bay in 2017 (*c*) (literature data [22]) were determined. Specimens smaller than 1 mm were not recorded. Bivalves were weighed after they had been opened and the fixing solution had been removed from the mantle cavity.

In recently collected sediment samples, pH and Eh were determined using a pH-150MA meter and natural moisture was determined by weight method.

To determine hydrocarbons, marine sediments were air-dried under laboratory conditions, ground in a mortar and sieved through a sieve with a mesh diameter of 0.25 mm.

In air-dry samples, the amount of chloroform-extractable substances (CES) was determined by weight method, and PHCs were determined by IR spectrometry [3)] using an FSM-1201 spectrophotometer. All results obtained for the CES and PHCs concentrations were converted to 100 g of air-dry bottom sediment (ADBS). Correlation analysis was used for statistical processing of the material. The correlation coefficient was calculated at $P = 0.05$ in Microsoft Excel programme.

To determine the relationship between the analysed environmental parameters (Eh and pH), we used index rH_2 calculated for bottom sediments of the Sevastopol Bay waters using W.I. Clark's formula [22, p. 54]:

$$rH_2 = \mathrm{Eh} / 30 + 2\mathrm{pH}, \quad (1)$$

where Eh is redox potential; pH is hydrogen index.

To assess the role of mytilasters in the transfer of matter and energy on different substrates, we used the index of functional abundance (IFA) calculated by formula [23, p. 88]

$$\mathrm{IFA} = N^{0.25} \cdot B^{0.75}, \quad (2)$$

where B and N are biomass, $\mathrm{g \cdot m^{-2}}$, and abundance, $\mathrm{ind. \cdot m^{-2}}$, of the taxon.

The IFA for solid natural and artificial substrates of water areas with different anthropogenic load was calculated using data on abundance and biomass of mytilasters from literature sources [10, 15, 18, 20, 24, 25] for 2012–2018. For the bottom sediments of Sevastopol Bay, this index was calculated according to the indicators we obtained in the present work (monitoring surveys in 2012, 2015, 2018). For marine soils of Laspi Bay, the IFA was calculated using literature data.

Results and discussion

Settlement of Mytilaster lineatus on solid artificial and natural substrates under conditions of chronic petroleum pollution and in conditionally clean water areas

In the seawater of Sevastopol Bay, high concentrations of PHCs have been recorded [10, 18], which indicates their constant inflow into the water area. In [19], regular exceeding of sanitary norms for this indicator was noted (see Table 1).

[3)] Oradovskiy, S.G., ed., 1977. [*Guideline for Methods of Sea Water Chemical Analysis*]. Leningrad: Gidrometeoizdat, p. 118–131 (in Russian).

In 2008–2010, the amount of these compounds in water exceeded the MPC on average by 1.5–2 times in 80% of all cases.

Mytilid fouling is ubiquitous on the mooring walls of Sevastopol Bay. Its community undergoes a number of changes under the influence of natural and anthropogenic factors. At the same time, the degree of influence of one or another factor on mytilid communities is variable. Thus, significant changes in fouling were noted after the devastating storm in Sevastopol on 11 November 2007. As shown in [9], mytilid communities on the mooring walls of Sevastopol Bay were almost completely destroyed. Since 2008, they have been gradually recovering in the environment with chronic petroleum pollution, but full recovery of biocenoses took quite a long time.

It was noted [9] that in the spring of 2009, the average abundance of mytilasters on the mooring walls of the bay had increased significantly relative to 2008 and had reached pre-storm values of 2006. In 2006–2009, the abundance of mytilasters increased one and a half to two times in some areas of the bay. The mollusks did not differ in size composition then. It should be noted that the abundance of mussels on the mooring walls decreased by half during the same period.

By 2015, at the same stations, mussel abundance and biomass had declined significantly relative to 2006, with abundance at some stations decreasing four times and biomass six times. These indicators in mytilasters changed to a lesser extent on the surface of the hydraulic structure than in mussels. A twofold increase in the number of abundance and biomass of mytilasters was observed at almost all studied sections of the promenade. In [13], it is noted that in 2015, mytilasters were more numerous than mussels on the concrete promenade of the bay and this phenomenon is frequent for fouling of artificial structures in the Sevastopol waters. Based on the above, it can be noted that under the conditions of regular exceedance of PHCs concentrations in seawater, the community of mytilasters on the mooring walls of Sevastopol Bay recovered after the storm faster than the mussel community. In 2018, a decrease in the abundance and biomass of the studied mollusks was observed at the hydraulic structures of the inner part of the Sevastopol Bay waters compared to 2015 [21]. At the same time, the size composition of the mytilasters has not generally changed over the period under study.

Information on mytilid fouling on artificial substrates of Laspi Bay (mooring walls, concrete slabs and pier of the Laspi children resting camp) is fragmentary or not available. In the waters of Laspi and Sevastopol bays, experiments [26] were conducted to study the potential replenishment of the settlements of mussels and mytilasters during the periods of mass settling of their larvae in different periods. The experiment showed that in the coastal waters of Laspi Bay on artificial substrates (plates with smooth and pile surface), the replenishment of settlements of mytilasters was much higher than in Sevastopol Bay. Potential replenishment of mytilasters in conditionally clean and polluted water areas is higher than that of mussels. Besides the substrate, the reason influencing the difference in mollusk settlements in conditionally clean and chronically petroleum-polluted water areas can be the quality of their habitat.

Studies [24] of fouling of hydraulic structures in the area of the Southern pier of Sevastopol Bay and a conditionally clean area on the breakwater at the open coast of the town of Alupka (Southern Coast of Crimea (SCC)) showed that the abundance of this species in polluted seawater at the Sevastopol coast was almost twice as high as at the Alupka coast (see Table 1). The biomass of mytilasters in both areas is almost the same. This can be stipulated by the fact that water temperature rises faster in Sevastopol Bay during the spring and summer period than near the SCC. Consequently, the breeding period in the bay can start earlier and more juveniles can settle down by July–August. Such high numbers of mytilasters in the polluted waters indicate that this species is resistant to petroleum pollution and that this anthropogenic factor is not determinant for the functioning of the community. The priority factors affecting the abundance of mollusks are hydrodynamic processes and temperature regime.

Mytilasters are common in waters with different degrees of marine pollution. Thus, we observed mytilasters on rocks in the Laspi Bay waters, where the PHCs concentration in seawater in 2018 was close to the maximum permissible one (MPC = 0.05 $mg \cdot L^{-1}$) [20] and exceeded the MPC 3–4 times in summer (see Table 1). On average, the PHCs concentration was higher than concentrations typical for Sevastopol bays. At the same time, our studies of hydrocarbon composition of the Batiliman seawater in the period of different recreational load (Laspi Bay) in 2023 [27] showed the absence of petroleum pollution in the water area, and high PH indicators were most likely associated with natural processes (active intake of allochthonous compounds). No petroleum pollution is also indicated by the trace PHCs concentrations in marine soils of Laspi Bay in 2016–2018 [20].

Mytilid fouling of natural hard substrates along the Crimean coast, especially in the SCC waters, has been insufficiently studied in the modern period. The main works in this direction are devoted to the study of the Karadag benthos. In 2014, a study of the taxonomic composition and quantitative indicators of mytilids inhabiting natural substrates of the Cape Martyan Reserve was carried out [28]. The *Mytilaster lineatus* bivalves dominated in terms of quantitative indicators (47% of total abundance and 97% of total macrozoobenthos biomass). This species of mollusks predominates on solid substrates in other areas of the Crimean coast as well. Nevertheless, it is worth noting that the abundance and biomass quantitative indicators of mytilasters (see Table 1) on artificial substrates in the Sevastopol Bay waters are significantly higher than on the SCC natural substrates [2, 13, 26].

The highest IFA values were obtained for the Sevastopol Bay artificial substrates (Table 1). The lowest values were recorded on the SCC natural substrates. This suggests that mytilasters inhabiting the bay hydraulic structures contribute more to the transformation of matter and energy than mytilasters inhabiting

T a b l e 1. Average abundance and biomass of *Mytilaster lineatus* mollusks on artificial and natural substrates with different levels of petroleum pollution (2012, 2015, 2018)

Parameter	Artificial substrates			Natural substrates	
	Sevastopol Bay		Breakwater, Alupka	Karadag	Southern Coast of Crimea
	Southern pier	Promenade			
Abundance, ind.·m^{-2}	11,425	28,388	5654	11,830	9136
Biomass, g·m^{-2}	869	1705	705.1	1700	593.9
Pertroleum hydrocarbons concentration in water, mg·L^{-1}	0.3	0.16	0.1	0.024	0.14
IFA	1655	3444	1186	2761	1176

natural rocks. In general, the values of this index specify that in water areas exposed to chronic petroleum pollution, the contribution of mytilasters to the community is more significant than in conditionally clean water areas.

It can be concluded that the abundance of mytilasters on hard substrates is probably primarily influenced not by marine pollution, but by water temperature and surf-wave phenomena. In addition, it is worth noting that this mollusk is resistant to organic pollution. Its abundance and biomass in the fouling of water areas chronically polluted with petroleum and petroleum products corresponds to and in some areas exceeds these indicators in conditionally clean areas.

Settlement of Mytilaster lineatus on soft soils under conditions of chronic petroleum pollution and in conditionally clean water areas

The studied mollusks do not form mass settlements in muds, but it is known that species diversity of benthic communities can be used to assess the water area ecological conditions, in particular, presence of filter-feeding bivalves, indicating the environmental quality, in the community. Under conditions of chronic petroleum pollution and deterioration of physical and chemical parameters of marine soils, the density of settlement of mytilids decreases [3]. Earlier studies of the Sevastopol

Bay benthic community (2000–2009) showed significant deterioration of the general status of macrozoobenthos: decrease in total biomass in almost all selected water areas [29].

Changes were also noted for mollusks M. lineatus. In 2000, they made a significant contribution to the total biomass and abundance of macrozoobenthos, whereas in 2009, these indicators decreased two times. The key factors influencing the formation and composition of benthic animal biocenoses include the oxygen level in marine soils, salinity, bottom sediment composition, the PHCs and heavy metals level in water and bottom sediments and their accumulation in mollusks [7]. Mytilasters make a great contribution to the total biofilter volume and, consequently, to the processes of self-purification of the water area [3]. They accelerate significantly sediment deposition to the bottom due to their filtration activity.

According to the results of our surveys, mytilasters were found in the Sevastopol Bay bottom sediments represented mainly by black or dark grey muds, sometimes with admixture of sand and broken shell (in 2012 in 58% of samples, in 2015 and 2018 in 50% of samples) (Table 2). In most cases, mytilasters were recorded in muddy bottom sediments, less frequently in sandy sediments with admixture of fine shell. It was noted that mollusks had the lowest biomass in sandy soils.

In 2012, the abundance of mytilasters in the Sevastopol Bay muds varied from 9 to 70 ind.·m^{-2} (Table 2). The highest density of mollusks was recorded in the bay coastal zone in its southwestern part (st. *13*). This station is located at one of the most polluted sites near the mooring walls of Artilleriyskaya Bay (Figure, *a*).

Table 2. The abundance *N* and biomass *B* of *Mytilaster lineatus* mollusks in the bottom sediments of Sevastopol Bay with physico-chemical indicators of their habitat

Year	*N*, ind.·m^{-2}	*B*, g·m^{-2}	pH	Eh, mV	*H*, %	CES, mg·100 g^{-1}	PHCs, mg·100 g^{-1}	IFA
2012	9–70 / 29.14	0.002–0.184 / 0.04	7.2–8.2 / 7.6	–181…–19 / –91	36–68 / 45	100–2200 / 920	55–799 / 317	0.22
2015	9–26 / 16.17	0.002–0.096 / 0.03	7.3–8.2 / 7.7	–236…+292 / 19.3	31–71 / 58	140–2280 / 1153	110–887 / 514	0.13
2018	9–79 / 36	0.006–0.43 / 0.09	7.6–7.9 / 7.8	–188…+24 / –65	52–68 / 60	200–2200 / 871	134–592 / 477	0.42

Note: 1. The range of values is in the numerator, the average value is in the denominator.
2. *H* – natural humidity.

The ferry pier and stormwater outfall are located here. The CES concentration at this station was 540 mg·100 g^{-1} ADBS, that of PHCs was 301.7 mg·100 g^{-1} ADBS. These indicators correspond to the 4^{th} level of bottom sediment pollution according to the regional classification [25]. The biomass of mytilasters during this period was within the range of 0.002–0.184 g·m^{-2} (Table 2).

The range of mollusk abundance in 2015 was from 9 to 26 ind.·m^{-2} (Table 2). The density of mytilasters decreased insignificantly compared to 2012. The abundance of mollusks decreased by half in the central part of the bay at st. *8* (Figure, *a*) and by 2.5 times in the southwestern part of the bay (st. *13*). At the same time, relative to 2012, at st. *13*, the CES value increased by four times and the PHCs concentration increased more than twice. The pollution level at this station corresponds to the highest 5^{th} level, whereas earlier the CES content corresponded to the 4^{th} level.

In the bottom sediments of Yuzhnaya Bay, on the shores of which the piers were built (st. *10*) (Figure, *a*), the density of mollusks increased from 18 to 26 ind.·m^{-2}. At the same time, the CES concentration at this station decreased from 2200 to 1800 mg·100 g^{-1} ADBS relative to 2012. Nevertheless, the level of bottom sediment pollution remained the same and corresponded to the 5^{th} level. The biomass values of the studied mollusks in 2015 ranged from 0.002 to 0.096 g·m^{-2} (Table 2). Furthermore, while the abundance of mytilasters in the central part of the bay (st. *8*) decreased, their biomass here increased three times. The CES and PHCs indicators at this station decreased significantly. In other parts of the water area, their values differed slightly.

In 2018, the abundance of mollusks ranged from 9–79 ind.·m^{-2} (Table 2). In comparison with the data of previous years, the density of settlement of mytilasters increased at all stations, except for st. *11* (central part of Yuzhnaya Bay) (Figure, *a*). In 2018, compared to the 2015 data, the level of organic pollution of bottom sediments in the Yuzhnaya Bay water area decreased, the PHCs concentration decreased by 4.5 times. At the same time, as in previous years, the level of bottom sediment pollution corresponded to the highest 5^{th} level.

In the southwestern part of the bay (st. *13*), the abundance of mollusks approached the values of 2012 and was 2.5 times higher than in 2015. The CES and PHCs concentrations were almost unchanged from 2015 to 2018 at this station, but their values were high and corresponded to the 5^{th} level of pollution. The 2018 biomass values ranged from 0.006 to 0.43 g·m^{-2} (Table 2).

In the central part of the bay (st. *7*) (Figure, *a*), the biomass of mytilasters became four times higher compared to 2012. During the same period, the CES indicators remained almost unchanged, while the PHCs concentration increased by six times. These values also correspond to the 5^{th} level of marine soil pollution.

At other stations, a tendency for an increase in the biomass of mytilasters was noted, except for the indicators in the central part of Yuzhnaya Bay (st. *11*) and the southwestern part of Sevastopol Bay (st. *13*). The biomass value in 2018 at st. *11* decreased almost three times compared to 2015, while at st. *13*, the mollusk biomass decreased almost five times, in contrast to the 2012 data. The abundance of mytilasters was almost the same during this period. At the same time, the CES indicators at the studied stations during the same period corresponded to the 5^{th} level of pollution.

The abundance and biomass of mollusks in the years under analysis varied unequally. In general, the analysis of the abundance and biomass average values of the studied mollusks from 2012 to 2018 showed that the abundance of mytilasters in the marine soils of Sevastopol Bay had slightly increased. The average abundance during the study period increased from 29 to 36 ind.$\cdot$m^{-2}, while the biomass increased from 0.04 to 0.09 g$\cdot$m^{-2}.

The IFA for marine soils of Sevastopol Bay in the studied years (2012, 2015 and 2018) was 0.22, 0.13 and 0.42, respectively (Table 2). According to this index, in 2018, the contribution of mytilasters to the transformation of matter and energy was higher than in the previous years. In general, the IFA values are very low, indicating an insignificant energetic role of mytilasters inhabiting the Sevastopol Bay soft soils.

In addition to substrate, as mentioned above, community functionality is influenced by physical and chemical indicators that either accelerate or slow down oxidation processes in bottom sediments, thereby changing oxygen levels.

In 2012, pH in bottom sediments ranged from 7.2–8.2, in 2015 it was 7.3–8.2, and in 2018 it was 7.6–7.9 (Table 2). The pH range in these years indicated slightly alkaline environment in most of the analysed samples, except for the Yuzhnaya Bay coastal area (st. *10*) and near Konstantinovsky ravelin (Northern pier) (st. *17*) (see Figure, *a*), where pH increased to 8.21–8.22 (st. *10* in 2012 and 2015, respectively) and 8.2 (st. *17* in 2015), which is likely to be related to the type of precipitation.

The redox potential (Eh) in 2012 had negative values and ranged from −19 to −181 mV (Table 2), indicating reducing environmental conditions. In 2015, Eh fluctuated within a wide range from −116 to +292 mV (Table 2). In the central part of Sevastopol Bay (sts. *5*, *8*) and in the coastal zone of Yuzhnaya Bay (st. *10*) (see Figure, *a*), Eh indicated poorly reducing conditions. In the central part of Yuzhnaya Bay (st. *11*) and in the coastal zone of the southwestern part of Sevastopol Bay (st. *13*) (see Figure, *a*), Eh indicated reducing conditions, whereas at the Northern pier (st. *17*) (see Figure, *a*) it indicated oxidative ones. As in 2015, Eh had a large range from −188 to +24 mV in 2018 (Table 2). At all stations, except for the coastal zone of Sevastopol Bay (st. *13*) (see Figure, *a*), poorly reducing conditions were noted, with st. *13* having the lowest Eh value indicating reducing environmental conditions. These conditions contribute to the accumulation of hydrocarbons, as at low values of the environment redox potential, the processes of bitumoid transformation are slowed down. Reduced Eh values correspond to the water areas where organic matter is concentrated [30].

It is known that Eh value depends on pH. To obtain comparable data in the analysed bottom sediments with different pH values, we calculated the hydrogen potential index (rH_2) using W.I. Clark’s formula (1). According to this gradation, oxidative processes predominate at rH_2 above 27, reducing processes at 22–25 and intensive reducing processes below 20. In our case, only one station (st. *17* in 2015) (see Figure, *a*) showed rH_2 close to 27, hence, oxidative processes prevailed at this station (Northern pier). At other stations, the rH_2 values were significantly lower than 20 during the study period, which indicates intensive reducing processes in the studied marine soils.

Natural moisture content in bottom sediments was 36–68% in 2012, 31–71% in 2015 and 52–68% in 2018 (Table 2). These values correspond to the particle size distribution of bottom sediments. In general, reducing environmental conditions and high concentrations of organic matter accumulated in sediments are observed at most stations in terms of physical and chemical parameters: CES in the range of 100–2280 mg·100 g^{-1} ADBS (Table 2). Widespread occurrence of mytilasters under these conditions confirms the tolerance of mollusks to organic pollution.

In the correlation analysis, only those stations of Sevastopol Bay at which mytilasters had been found were taken into account (n = 15). In 2012, no correlation between mollusk abundance, biomass and physical and chemical parameters of bottom sediments was detected. In subsequent years (2015–2018), a direct relationship between the abundance and CES and PHCs concentration was observed, with correlation coefficients r equal to 0.94 and 0.85, respectively (Table 3). A reverse relationship is observed between abundance and Eh (r = −0.79). The strongest direct correlation was with the CES concentration (r = 0.94). In 2015, a direct correlation between the CES concentration and mollusk biomass was observed (r = 0.72). In 2018, a direct correlation was observed between the biomass of mytilasters and Eh (r = 0.6). An increase in the abundance (2015, 2018) and biomass (2015) of mytilasters at elevated CES concentrations can be observed from the correlation data obtained.

It is known that at high levels of organic pollution (4th, 5th) degradation and reorganisation of biocenoses occurs [25]. Starting from the 3rd level of pollution, the trophic structure of benthos is sharply changed, a change in its qualitative

Table 3. Correlation coefficients between the abundance and biomass of *Mytilaster lineatus* mollusks and the physico-chemical parameters of the environment

Characteristic	Year	pH	Eh, mV	*H*, %	CES, mg·100 g^{-1}	PHCs, mg·100 g^{-1}
Abundance	2012	−0.32	0.25	0.10	0.03	−0.18
	2015	0.14	−0.79	0.38	0.94	0.85
	2018	−0.47	−0.04	−0.60	0.72	0.89
Biomass	2012	−0.26	0.39	0.20	−0.05	−0.19
	2015	−0.59	−0.34	0.30	0.72	0.40
	2018	0.04	0.60	−0.30	0.23	0.43

composition is observed: some species are eliminated from the community and more resistant to pollution species occupy dominant positions. The increase in the quantitative indicators of mytilasters at the high 5th level of pollution indicates the resistance of this species to organic pollution. Despite the fact that such dependence was observed in the water area with high anthropogenic load, the quantitative indicators in Sevastopol Bay were lower than in conditionally clean water area (Laspi Bay).

For comparison: in the conditionally clean water area of Laspi Bay, the average abundance of mytilasters was 126 ind.$\cdot$m^{-2} and the biomass – 3.5 g$\cdot$m^{-2} [31]. The IFA for the Laspi Bay marine soils was 8.57, which makes it possible to speak about a greater energetic contribution of the studied mollusks in the conditionally clean water area than in the water area with chronic petroleum pollution. In Laspi Bay, bottom sediments are represented mainly by sands. The CES content in them on average did not exceed 42 mg$\cdot$100 g^{-1} air-dry matter, which corresponds to the 1st level of pollution [20]. Despite the exceeding of MPCs of PHCs in seawater in recent years, PHCs in sandy soils were recorded at trace concentrations [20]. Moreover, the CES and PHCs levels in the Laspi Bay bottom sediments remain within the range close to the level of the 1980s, which indicates stable favourable environmental situation in the area. In 2015, the quality of marine waters was assessed using hydrochemical indicators of Sevastopol and Laspi bays. It was established that in some areas of Sevastopol Bay, bottom waters had been in the state of hypoxia, in contrast to the waters of Laspi Bay [4)]. It is also known that sandy soils are more oxygenated than muds. In the latter, in turn, the processes of accumulation of organic substances, including petroleum hydrocarbons, occur faster, which directly affects the quality of bottom sediments and, consequently, the density of settlement and biomass of mollusks.

Conclusion

Mytilasters inhabit various water areas with different degrees of marine pollution by petroleum and petroleum products. These mollusks are widespread, form mass settlements on artificial and natural hard substrates, inhabit muddy and sandy bottom sediments. Due to their abundance, the studied mollusks form a powerful natural biofilter, influencing the marine environment self-purification potential.

The abundance of mytilasters inhabiting hard natural and artificial substrates is primarily influenced not by marine pollution but by water temperature and surf-wave phenomena. This mollusk is resistant to organic pollution, its average abundance (28,388 ind.$\cdot$m^{-2}) and biomass (1705 g$\cdot$m^{-2}) at the hydraulic structures of Sevastopol Bay were at the same level under conditions of chronic petroleum pollution of the water area. However, in some areas they were higher than in conditionally clean areas (SCC water area). At the same time, the correlation between

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[4)] Korshenko, A.N., ed., 2023. *Marine Water Pollution. Annual Report 2021*. Moscow: SOI, 228 p. (in Russian).

the abundance and biomass of mytilasters inhabiting artificial substrates in the bay and the PHCs concentrations in seawater is not observed. The highest IFA values were obtained for the artificial substrates of Sevastopol Bay, which indicates a significant contribution of mytilasters inhabiting these substrates under conditions of chronic petroleum pollution to the transformation of matter and energy.

Analysis of the average values of abundance and biomass of mytilasters in the studied years showed that the number of mollusks in the Sevastopol Bay marine soils had increased at constantly high concentrations of CES (140–2280 mg·100 g^{-1}) and PHCs (110–887 mg·100 g^{-1}). In 2015 and 2018, a direct correlation between the abundance of mytilasters and the level of organic matter contamination of bottom sediments was found (correlation coefficient *r* was 0.94 for CES and 0.85 for PHCs).

The functionality of the benthic community is influenced by the physical and chemical parameters of bottom sediments, which either accelerate or slow down the oxidation processes, thereby changing the oxygen level. The most important indicator affecting mollusk abundance and biomass is the redox potential of bottom sediments, which was found to be directly dependent on it ($r = 0.6$). As for other indicators (pH, natural moisture), such a relationship was absent or expressed weakly.

It was revealed that in bottom sediments of conditionally clean water area of Laspi Bay with minimal level of petroleum pollution (PH concentrations in bottom sediments did not exceed 5 mg·100 g^{-1}), the average abundance and biomass of mytilasters had been higher than on the Sevastopol Bay soils with chronic petroleum pollution of marine soils and high CES and PH concentrations in bottom sediments corresponding to the 5^{th} level of pollution.

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Tatiana V. Viter – participation in monitoring surveys of the bay, determination of abundance and biomass of mytilasters in bottom sediments of Sevastopol Bay for 2012–2018, discussion of the results, writing of the article

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