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Original paper

Self-Purification Capacity of the Yalta Port Ecosystem in Relation to Inorganic Forms of Nitrogen for 2012–2022

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Abstract
A database of nutrients and dissolved oxygen for 2012–2022 was formed from long-term monitoring results of the hydrochemical indicators of the Yalta Port water area. The paper shows dynamics of nutrients for the studied water area and determines inorganic forms of nitrogen (nitrites, nitrates, ammonium) as priority pollutants in the port ecosystem. The self-purification capacity of the Yalta Port water ecosystem was assessed by calculating the specific assimilation capacity (AC_{sp}) in relation to nitrates, nitrites and ammonium using the balance method. The rates and times of removal of these inorganic nitrogen forms from the mentioned ecosystem were calculated. The paper analyses the obtained AC_{sp} values for the Yalta Port water ecosystem for two periods (2012–2017 and 2018–2022). The study shows that for nitrates, there is an increase in AC_{sp} from 31.49 to 36.07 μg/(L·day) for these periods, respectively. The same dependence was established for nitrites. For this nitrogen form, the change in AC_{sp} ranged from 0.08 to 0.1 μg/(L·day). As for ammonium, an inverse relationship was observed for these periods: a decrease in the AC_{sp} value from 8.67 to 7.56 μg/(L·day). The paper compares the obtained AC_{sp} values in relation to inorganic forms of nitrogen for the Yalta Port water ecosystem with similar values for the Sevastopol Bay ecosystem, which is under high anthropogenic load, affected by river runoff and has limited water exchange with the open sea. The more intensive hydrodynamic regime is suggested to account for the higher self-purification capacity in relation to inorganic forms of nitrogen in the Yalta Port ecosystem (as part of Yalta Bay) if compared with Sevastopol Bay.

Keywords: nutrients, biogenic nitrogen, ecosystem, self-purification capacity, assimilation capacity, Yalta Port

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Самоочистительная способность экосистемы Ялтинского порта в отношении неорганических форм азота за 2012–2022 годы

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Аннотация

По результатам многолетнего мониторинга гидрохимических показателей акватории Ялтинского порта за 2012–2022 гг. сформирована база данных о концентрации биогенных элементов и растворенного кислорода за указанный период. Для исследуемой акватории показана динамика содержания биогенных элементов и выделены неорганические формы азота (нитриты, нитраты, аммоний) как приоритетные загрязняющие вещества в экосистеме порта. Оценка самоочистительной способности экосистемы акватории Ялтинского порта выполнена путем расчета балансовым методом величины удельной ассимиляционной емкости ($АЕ_{уд}$) в отношении нитратов, нитритов и аммония. Рассчитаны также скорости и время удаления этих неорганических форм азота из указанной экосистемы. Проанализированы полученные значения $АЕ_{уд}$ для экосистемы акватории Ялтинского порта за два периода: 2012–2017 и 2018–2022 гг. Показано, что в отношении нитратов наблюдается увеличение $АЕ_{уд}$ от 31.49 до 36.07 мкг/(л·сут) за указанные периоды соответственно. Такая же зависимость установлена для нитритов: изменение $АЕ_{уд}$ составило от 0.08 до 0.1 мкг/(л·сут). В отношении аммония за указанные периоды наблюдается обратная зависимость – уменьшение $АЕ_{уд}$ от 8.67 до 7.56 мкг/(л·сут). Приведены результаты сравнения полученных значений $АЕ_{уд}$ в отношении неорганических форм азота для экосистемы акватории Ялтинского порта с соответствующими показателями для экосистемы б. Севастопольской, которая характеризуется высокой антропогенной нагрузкой, подвержена влиянию стока рек и имеет затрудненный водообмен с открытым морем. Высказывается предположение, что причиной более высокой, чем у экосистемы б. Севастопольской, способности к самоочищению в отношении неорганических форм азота экосистемы Ялтинского порта (как части Ялтинского залива) является более интенсивный гидродинамический режим.

Ключевые слова: биогенные элементы, биогенный азот, экосистема, самоочистительная способность, ассимиляционная емкость, Ялтинский порт

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Introduction

The coastal waters of the Southern Coast of Crimea, in particular Yalta Bay, being recreational and resort areas, experience significant anthropogenic pressure with pronounced seasonality.

The Yalta Port water area, with depths of up to 8.5 m, is part of Yalta Bay and is bounded by a harbour with a protective breakwater. The water area is under additional anthropogenic pressure due to year-round navigation in the port and runoff from mountain rivers. As a result, higher concentrations of pollutants, including nutrients (phosphates, nitrates, nitrites, ammonium and silicon), are observed in the Yalta Port waters compared to similar indicators in the entire Yalta Bay.

The eutrophication level for the aquatic environment is determined by the distribution of biogenic nitrogen and phosphorus compounds, their seasonal and annual variations and recirculation degree. The sources of inorganic nitrogen (nitrites, nitrates and ammonium) entering the sea are river waters, domestic and industrial effluents and atmospheric precipitation. The nitrogen cycle in the surface layer of water is associated with nitrification $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$ and ammonification $NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+$.

To date, numerous studies have been devoted to the hydrological and hydrochemical characteristics of the coastal waters of the Southern Coast of Crimea, including Yalta Bay. Work [1] summarises information on the hydrometeorological conditions of the Yalta coastal zone based on all observation data from 1870 to 2003 and on the hydrochemical regime in 1986–2004. Work [2] compares the hydrochemical characteristics of two water areas (the Yalta Port area and Yalta Bay) analysing the annual dynamics of concentrations of biogenic substances (nitrogen NO_2^-, NO_3^-, NH_4^+, N_{tot}, phosphorus PO_4^{3-}, P_{tot} and silicon SiO_2) as well as dissolved oxygen (O_2) and water temperature in the surface layer for 1987–2004 and 2005–2010. The presented results show changes in the ecological state of the surface water layer of Yalta Port during the study periods.

The inflow of significant amounts of nutrients and pollutants into Yalta Bay is caused by the runoff from the mountain rivers: Derikoyka (Bystraya) and Uchan-Su (Vodopadnaya) with their tributaries, Lyuka (which supplies water to Yalta), and others [1)]. Of note, according to work [3, p. 61], "the Vodopadnaya River mouth and the adjacent waters of Yalta City Beach are in an area of ecological risk due to elevated levels of nitrates and nitrites in the river water and severe bacterial contamination by *Escherichia coli* in the seawater (several hundred-fold above sanitary standards values during the high season)". According to the data [1)], the channel, floodplain and mouth of the Bystraya River and the adjacent water area of the Yalta

[1)] Borisova, Yu., 2014. The Uchan-Su River. In: Yu. Borisova, 2014. *Plantarium. Plants and Lichens of Russian and Adjusted Countries: The Open Online Plant Atlas and Field Guide.* Available at: https://www.plantarium.ru/page/landscapes/point/2563.html [Accessed: 29 August 2025] (in Russian).

passenger seaport are in an ecological risk zone. Elevated levels of nitrates and nitrites were recorded in the river water. The seasonal dynamics of inorganic nitrogen and phosphorus in the mouth zone of the Vodopadnaya River was studied in work [4]. The studies revealed that nutrient concentrations in the freshwater of the estuary significantly exceeded those in the seawater: nitrites (7.2-fold), ammonium (3.0-fold), nitrates (62.9-fold), and mineral phosphorus (13.2-fold). The total mineral nitrogen concentration in the river water was 27.9 times higher than in the seawater.

Currently, comprehensive monitoring of the background environmental condition in the coastal waters of Crimea, especially in the areas adjacent to the infrastructure of cargo, passenger, fishing and military fleets. Therefore, a proper assessment of the baseline condition is difficult.

The effectiveness of natural self-purification of marine ecosystems is determined by interdependent processes, such as input of pollutants, their deposition in bottom sediments and interaction with marine aerosols, the redistribution of pollutants and their transformation by biota, and the dynamic removal of pollutants beyond the water area. Under intense anthropogenic pressure, the first step towards normalising the ecological status of shallow marine waters is to assess their self-purification capacity by calculating the assimilation capacity (AC) of the ecosystem in relation to a priority pollutant or complex.

The AC concept developed by Yu. A. Izrael and A. V. Tsiban [5], based on the results of comprehensive oceanographic studies, was tested on the Baltic Sea ecosystem for benz(a)pyrene, polychlorinated biphenyls and a number of toxic metals (Cu, Zn, Pb, Cd, Hg). According to [5], the AC indicator characterises the ability of a marine ecosystem to withstand the addition of a certain amount of pollutants without developing irreversible biological consequences. AC has the dimension of a substance flux (mass of substance per unit of volume per unit of time). As shown in [6, 7], when using the balance method for calculating AC, the most difficult task is calculating the integral residence time of pollutants in the ecosystem under study. This quantity depends largely on the physical and chemical properties of a particular pollutant, the hydrodynamic parameters of the water area, and the set of processes (physical, chemical, microbiological) responsible for destruction of the pollutant or its removal beyond the boundaries of the water area under study.

The work is aimed to determine the priority pollutant based on the results of long-term monitoring of nutrients in the Yalta Port water area and to assess the self-purification capacity of the ecosystem by calculating the specific AC (AC_{sp}) in relation to inorganic forms of nitrogen (NO_3^-, NO_2^-, NH_4^+).

Notably, a literature data analysis reveals that this study provides the first calculation of this kind for the ecosystem of the Yalta Port water area.

Materials and methods of the study

To achieve our objective, a database on the Yalta Port water area was created. It was based on materials from the annual reports Sea Water Quality by Hydrochemical Indicators for 2018–2022 by the Federal State Budgetary Institution State Oceanographic Institute [2)] and materials from the database of Marine Hydrophysical Institute. According to work [2)], hydrochemical studies of the biogenic complex were carried out by the Yalta Environmental Pollution Monitoring Laboratory using methods approved by the Roshydromet hydrochemical monitoring system [3)].

Samples were collected in the Yalta Port water area at a single point with a depth of 6 m at the base of the breakwater annually from January to December, with standard hydrological monitoring conducted every ten days. Trends in the seasonal and long-term dynamics of nutrients and dissolved oxygen against the background of changes in temperature and salinity of the surface and bottom water layers of the Yalta Port water area for 2018–2022 were considered. Changes in the ecological situation in the water area were assessed compared to the previous period of 2013–2017 [8].

The analysed database consisted of 1,920 measurements of total nitrogen and phosphorus content, mineral nitrogen complexes (nitrites, nitrates, ammonium), phosphates, silicon and dissolved oxygen, as well as sea water temperature and salinity. The number of analysed samples and concentration limits are presented in Table 1.

The characteristics of the database for 2013–2017 are presented in work [2)]. In this study, AC was calculated using the balance method proposed by Yu. A. Izrael and A. V. Tsiban [5]. The authors of this paper have adapted the method for marine ecosystems where state hydrochemical monitoring is carried out [8], for example, in Sevastopol Bay with regard to inorganic nitrogen and phosphorus [9, 10]. According to [7], the final formulas for estimating the mean value $\overline{A}_{mi}$ and standard deviation $\sqrt{D[A_{mi}]}$ for AC of a marine ecosystem (m) in relation to the i-th pollutant are as follows:

$$AE_{mi} = \overline{A}_{mi} \pm \sqrt{D[A_{mi}]}, \tag{1}$$

$$\overline{A}_{mi} = \frac{Q_m \cdot C_{thr\,i}}{C_{\max i}} \cdot \bar{v}_i, \quad D[A_{mi}] = \left(\frac{Q_m \cdot C_{thr\,i}}{C_{\max i}} \right)^2 \cdot D[v_i], \tag{2}$$

where Q_m is the volume of water in the calculation area; $C_{thr\,i}$ is the threshold concentration of a pollutant; $C_{\max i}$ is the maximum concentration of a pollutant in the ecosystem; v_i is the rate of removal of a pollutant from the ecosystem, the average value $\bar{v}_i$ and dispersion $D[v_i]$ of which are determined according to

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2) Korshenko, A.N., ed., 2024. *Marine Water Pollution*. Annual Report 2022. Ivanovo: PresSto, 302 p. (in Russian).

3) Oradovsky, S.G., ed., 1993. *Guide on the Chemical Analysis of Sea Waters.* RD 52.10.243-92. Saint Petersburg: Gidrometeoizdat, 264 p. (in Russian).

T a b l e 1 . Characteristics of the used data for 2018–2022

Parameter	MPC	Average	Maximum (% of MPC)	Standard deviation
PO_4^{3-}, µg/L	50	12	48 (96)	8.48
P_{tot}, µg/L	–	54.9	172	34.76
NO_2^-, µg/L	24	3.7	15.4 (64)	2.80
NO_3^-, µg/L	9032	140	953 (11)	201.77
NH_4^+, µg/L	389	18.6	104 (27)	14.27
N_{tot}, µg/L	–	1157	4301	831.60
Si_2O_2, µg/L	368	265	1698 (461)	303.91
O_2, %	–	91	109	6.49
Salinity, ‰	–	16.98	19.41	2.52
Temperature, °C	–	17.1	26.7	5.87

Note. The number of samples taken to determine the nutrient concentrations is 120 for each parameter, and 360 for each of oxygen content, temperature and salinity.

the original algorithm [6, 7]. In the equation above, the most difficult part of calculating AC is the quantitative assessment of the integral residence time of a pollutant in the ecosystem under study.

For areas under state monitoring, including the waters of Yalta Bay and Yalta Port, work [7] suggests a method to estimate the residence time of pollutants in the ecosystem. This indicator is calculated as the ratio of the change in pollutant concentration per unit of time to its average concentration, as well as the average rate of pollutant removal, determined from the complete data set for a specific water area (in our case, Yalta Port). The specific rate of pollutant removal is estimated using the equation

$$\tau = C / v,$$

where τ is the residence time of a pollutant in the ecosystem; C is the concentration of a pollutant in seawater; ν is the specific elimination rate of a pollutant from the ecosystem.

The specific rate of pollutant removal from the ecosystem of the studied water area was determined by the change in pollutant concentration in seawater per unit of time using the formula

$$v_n = (C_n - C_{n+1}) / (t_n - t_{n+1}),$$

where v_n is the specific rate of pollutant removal from the ecosystem during the selected period of concentration decrease $t_n - t_{n+1}$; C_n is the concentration during the period t_n; C_{n+1} is the concentration during the period t_{n+1} ; for $n = 1, ..., N$, where N is the sample size. Using the ratio of the average concentration of the i-th substance under study and the average rate of its removal (for all selected periods), the integral time of the pollutant residence in the ecosystem is calculated:

$$\tau_i = C_{\text{av}.i} / v_{\text{av}.i}.$$

The calculation results from the above equations are shown in Table 2.

The reliability of the calculated AC values is ensured by the analysis of a large dataset from long-term monitoring observations (1,920 measurements) over 10 years. It should be noted that for the Yalta Port water area, some boundaries with adjacent water areas are not strictly defined (i. e., they are permeable), therefore, AC_{sp} per unit volume (1 dm^3) was calculated as a relative value characteristic of the central part of the port water area [7].

To calculate AC parameters, only data from the water area under consideration was used, which allowed for a better assessment of its response to pollutant inputs and its self-purification capacity compared to using MPCs, which are accepted for all marine ecosystems disregarding regional peculiarities.

The average values of all forms of inorganic nitrogen during the observation period did not exceed the corresponding MPCs. This allowed us to use these average values as a threshold level in calculating the self-purification capacity of the ecosystem under study, which is one of the prerequisites for using Izrael's balance method [5] for calculation, the second prerequisite being the availability of long-term monitoring data.

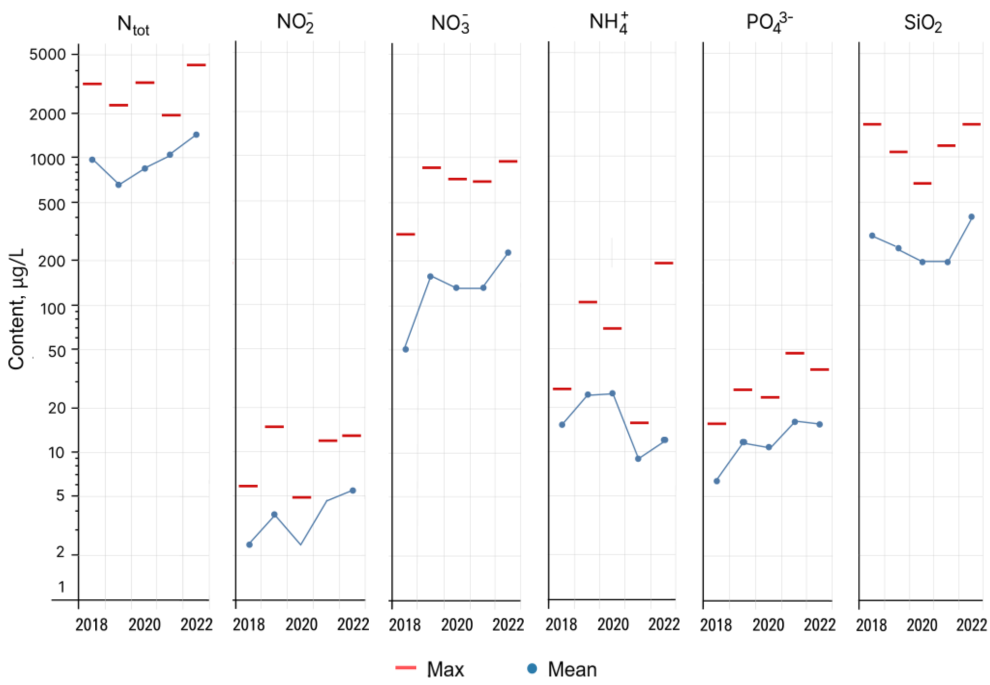
Results and discussion

During the study period, the salinity in the Yalta Port water area varied between 4.59 and 19.41 ‰, with strong desalination (less than 10 ‰) observed in the surface water layer in 2018, 2019, 2021 and 2022. Oxygen saturation remained consistently low (averaging 89–92%), resulting in a dissolved oxygen deficit of 25–37%. The actual concentration of dissolved oxygen varied significantly, ranging from 5.29 to 10.99 mg/L.

The average values for 2018–2022 for all mineral forms of nutrients did not exceed the MPC. As can be seen from Table 1, only the MPC for silicon was exceeded during the study period, which is quite understandable given the significant volume of fresh river water entering Yalta Bay [1)]. The maximum phosphate content in 2021 was close to the threshold value (96% of the MPC).

A single sample of surface water taken on 15 July 2022 in the port area contained high concentrations of nitrates and ammonium: 953 μg/L (0.11 MPC) and 190 μg/L (0.49 MPC), respectively. The maximum total nitrogen content in the surface waters of the port area during this period reached 20,779 μg/L, which is five times higher than that for other samples that year (4,301 μg/L) (Table 1) and previous years (1559–3266 μg/L) and is obviously associated with heavy rainfall and the transport of nutrients with river water from the catchment area [3, 4]. The nitrite content reached its maximum (15.4 μg/L) in 2019, when the second maximum of ammonium content (104 μg/L) was recorded, which in other years did not exceed 69 μg/L. The dynamics of average and extreme values of the studied nutrients for 2018–2022 are presented in Fig. 1.

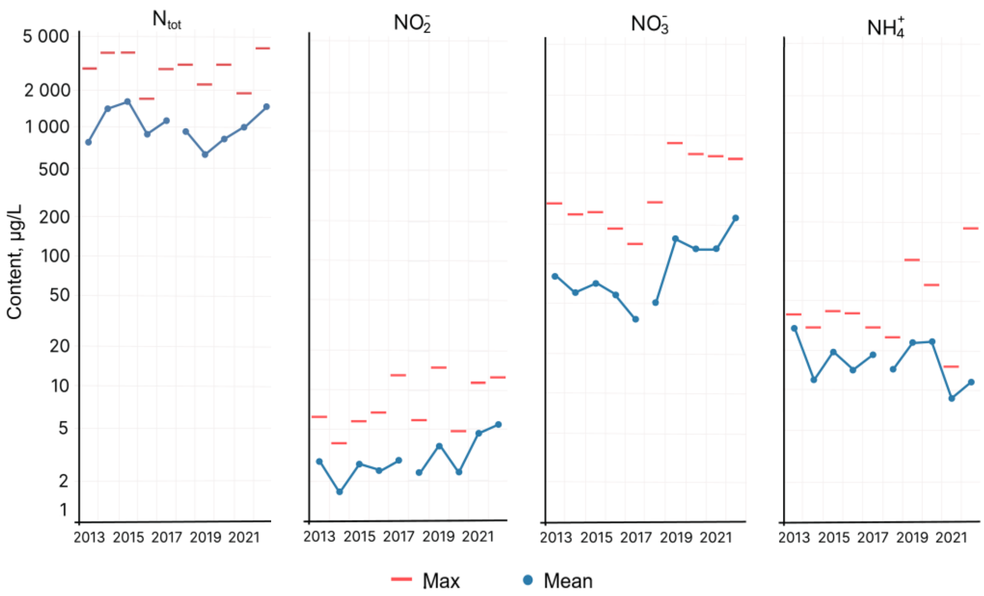
With relatively little change in the aeration of the waters (O_{2av}) of the Yalta Port water area during the described period, an increase in the average annual concentration of phosphorus and nitrogen was observed [8]. Thus, the total phosphorus content (P_{tot}) increased from 16 μg/L in 2018 to 77 μg/L in 2021, and that of nitrogen (N_{tot}) increased from 650 μg/L in 2019 to 1440 μg/L in 2022. Among mineral complexes, the maximum increase in the average annual concentration is characteristic of nitrates (from 51 μg/L in 2018 to 228 μg/L in 2022), while less noticeable for phosphates (from 6.5–11.7 μg/L in 2018–2020 to 15.7–16.3 μg/L in 2021–2022)



F i g . 1 . Long-term dynamics of average and extreme values of nutrients content in the water area of the port of Yalta in 2018–2022 and nitrites (from 2.4–3.8 to 4.7–5.5 μg/L in the specified years). The dynamics of ammonium nitrogen concentration showed a decrease from 24–25 μg/L in 2019–2020 to 9 μg/L in 2021.

An analysis of the database for 2018–2022 showed that inorganic forms of nitrogen (NO_3^-, NO_2^-, NH_4^+) were the priority nutrients in Yalta Port: their concentrations increased by 50–120% over five years (the dynamics of phosphates and silicon were not as pronounced), and their contribution to total nitrogen reached 70%. At the same time, comparative estimates of inorganic and total nitrogen content based on data for two periods (2013–2017 [8] and 2018–2022) showed a twofold increase in the total content of mineral forms of nitrogen (on average from 84 μg/L in 2013–2017 to 161 μg/L in 2018–2022) in the waters of Port of Yalta against a significant decrease in the total content of this pollutant (on average from 1212 to 996 μg/L for the specified periods) (Fig. 2). Due to the reduction in the organic component contribution, the total share of mineral nitrogen increased from 7 to 16%.

The created database allowed us to assess the self-purification capacity of the port's water ecosystem by calculating its AC for inorganic forms of nitrogen (nitrates and nitrites) that showed steady growth, as well as for ammonium, whose content changed insignificantly. The characteristics of the self-purification capacity of the marine waters of the Yalta Port ecosystem with regard to nitrates, nitrites and ammonium for 2013–2017 and 2018–2022 are presented in Table 2.



F i g . 2 . Content of inorganic and total nitrogen in the Port of Yalta water area in 2013–2017 and 2018–2022

T a b l e 2. Calculation results for the specific value of AC_{sp} in the ecosystem of the Port of Yalta water area in relation to inorganic forms of nitrogen for 2013–2017 and 2018–2022

Forms of nitrogen	Content, μg/L		v_n, μg/(L·day)	τ_i, day	AC_{sp}, μg/(L·day)
	mean	max			
2013–2017					
Nitrites (NO_2^-)	2.5	13.5	0.049	52–55	0.081
Nitrates (NO_3^-)	61.6	300.0	1.120	55–59	31.490
Ammonium (NH_4^+)	19.8	43.0	0.180	113–120	8.660
2018–2022					
Nitrites (NO_2^-)	3.7	15.4	0.065	58–60	0.097
Nitrates (NO_3^-)	140.0	953.0	4.210	33–37	36.070
Ammonium (NH_4^+)	16.5	104.0	0.220	81–83	7.560

As shown in Table 2, the average elimination time for nitrites from the Yalta Port water area in 2018–2022 was 58–60 days, while in 2013–2017 it was 52–55 days. In 2018–2022, the time required to remove nitrates and ammonium from the ecosystem decreased by approximately 20 and 30 days, respectively.

Nitrate removal occurs much faster. The removal rate varies widely: its maximum values for nitrites reach 0.302 μg/(L·day), nitrates – 9.86 μg/(L·day) and ammonium nitrogen – 2.95 μg/(L·day), which exceeds the average values for the period by 2.3–9.2 times.

An analysis of AC_{sp} dynamics showed that the ecological situation in the Yalta Port water area in terms of nitrite and nitrate concentrations in 2018–2022 improved compared to 2013–2017, but deteriorated in terms of ammonium content. The decrease in AC_{sp} for ammonium as a reduced inorganic form of nitrogen indicates an increase in the inflow of untreated municipal wastewater into the Yalta Port water area in the recent period.

To verify the obtained parameters of the self-purification capacity of the Yalta Port water area ecosystem, they were compared with the corresponding AC_{sp} values for the Sevastopol Bay ecosystem published in [10, 11]. For Sevastopol Bay as a whole, the AC_{sp} for nitrites was 0.047 μg/(L·day) and for nitrates it was 25.92 μg/(L·day). An analysis of the results showed that these values are lower than those obtained for the ecosystem of the Yalta Port water area (Table 2).

This indicates a more favourable state of the water area, apparently due to increased water dynamics.

The AC_{sp} value for ammonium in the Yalta Port water area was 7.56 μg/(L·day), which exceeded the average value for the Sevastopol basin (5.67 μg/(L·day)) and the value in the bay's most problematic eastern part (1.99 μg/(L·day)), which is affected by the Chernaya River runoff [11, 13].

The self-purification capacity for inorganic nitrogen was compared for Port of Yalta and Sevastopol Bay. Although they share common pollution sources (technogenic and recreational press, inflow with river waters), the Yalta Port ecosystem revealed a significantly greater self-purification potential. We attribute this difference to the distinct hydrodynamic conditions of these water areas.

Unlike Sevastopol Bay, which has limited water exchange with the open sea, Port of Yalta is characterized by complex hydrodynamic processes [13]. These are driven by the western and south-western currents of the Rim Current, which flow along the southern coast of Crimea. Furthermore, the interaction of the Rim Current's northern boundary with the shelf topography, such as capes and bays, significantly shapes the local circulation. Future research will focus on how this interaction affects the self-purification capacity of the Southern Coast of Crimea's coastal ecosystems.

Thus, the calculated AC_{sp} values for each form of inorganic nitrogen allow us to assess the self-purification capacity limit specifically for the ecosystem of the Yalta Port water area, in contrast to the uniform MPC adopted for all marine ecosystems disregarding local peculiarities.

When assessing the self-purification capacity of the Yalta Port water area ecosystem in cases of emergency discharge, the AC_{sp} should be used as a reference, which is 0.097 μg/(L·day) for nitrites, 36.1 μg/(L·day) for nitrates and 7.56 μg/(L·day) for ammonium nitrogen. Regulating discharges, given the established quantitative limits covering the entire range of disposal processes, will improve the environmental condition of the port's water area and, as a result, reduce the negative impact on Yalta Bay as a whole.

Conclusions

Based on long-term monitoring results (2012–2022), a database has been created on the content of nutrients and dissolved oxygen in the waters of Port of Yalta. We used this database to assess the dynamics of nutrients and identify inorganic forms of nitrogen (nitrites, nitrates, ammonium) as priority pollutants of the port ecosystem.

For the first time for this ecosystem, over two periods (2012–2017 and 2018–2022), the AC_{sp} for inorganic forms of nitrogen (nitrates, nitrites and ammonium) was estimated using the balance method, and the rate and time of their removal from the studied ecosystem were calculated.

The decrease in AC_{sp} for ammonium as a reduced inorganic form of nitrogen, obtained for 2018–2022, indicates that the amount of untreated municipal wastewater entered the Yalta Port water area during this period was greater than during the first period.

The AC_{sp} values, obtained for the ecosystem of the Yalta Port water area for 2018–2022 for all inorganic forms of nitrogen, were compared with similar indicators for the ecosystem of Sevastopol Bay, an area with high anthropogenic pressure and limited water exchange with the open sea.

The calculated AC_{sp} values for each form of inorganic nitrogen (nitrates, nitrites, ammonium) can be used by local authorities for quantitative and qualitative assessment of municipal and storm water discharge as main sources of these forms of nitrogen.

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Elena E. Sovga – study task statement, analysis of the method of assimilation capacity calculation, comparison of the assimilation capacity values of the ecosystems of Yalta Port and Sevastopol Bay, preparation of the manuscript

Tatiyana V. Khmara – calculations, discussion of the study results, data analysis and visualisation, article editing

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