Original article **DOI**: 10.29039/2413-5577-2023-1-31-47

Morphodynamics of Sevastopol Bays under Anthropogenic Impact

T. V. Efremova *, Yu. N. Goryachkin

Marine Hydrophysical Institute of RAS, Sevastopol, Russia
* *e-mail: efremova@mhi-ras.ru*

Abstract

The degradation of the Crimean shores under the influence of the anthropogenic factor has become a serious problem to overcome which significant efforts and financial resources are spent. The purpose of the article is to consider retrospectively the morphodynamics of Sevastopol bays under the influence of anthropogenic activity. We used materials of MHI RAS observations, satellite and aerial photographs, literary sources as well as a range of maps and plans, mainly of the 19th century. It is shown that the natural environment of Sevastopol bays has changed significantly as a result of anthropogenic activity. The greatest impact is noted in the area of Sevastopol Bay, where the shores have been subjected to significant anthropogenic impact (the removal of cliffs, concreting of the coastline, construction of piers, etc.). The shores, which can be classified as untransformed, have survived only on 1.1 km (or 3 %) of the original length of the coastline. The outer shores of the coastal bays have preserved their natural state to the greatest extent. Only 1.3 km (17 %) were subject to anthropogenic impact consisting in cutting and planning of cliffs and erection of coastal protection and beach-retaining structures. The shores of the coastal bays themselves were subject to a much greater impact. Only one of them preserves the average level of technogenic impact, whereas in three of them it is the maximum, and in three others it is extreme. Out of 33.5 km of the inner perimeter of the bays, about 10 km (30 %) remain relatively unchanged. It is noted that by now only 0.3 km or 10 % of the pre-existing shores with sandy beaches have remained in the region under consideration. It is observed that as a result of anthropogenic activity, the Sevastopol group of salt lakes, which were previously used medicinally, has been almost destroyed.

Keywords: Black Sea, Sevastopol bays, morphodynamics, anthropogenic impact, coastline, salt lake, accumulative shore, abrasion shore

Acknowledgments: The work was carried out under state assignment no. FNNN-2021-0005.

For citation: Efremova, T.V. and Goryachkin, Yu.N., 2023. Morphodynamics of the Sevastopol Bays under Anthropogenic Impact. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 31. 47. doi:10.29039/2413-5577-2023-1-31-47

Морфодинамика севастопольских бухт под воздействием антропогенной деятельности

Т. В. Ефремова *, Ю. Н. Горячкин

Морской гидрофизический институт РАН, Севастополь, Россия
** e-mail: efremova@mhi-ras.ru*

Аннотация
Деградация берегов Крыма под влиянием антропогенного фактора стала серьезной проблемой, на преодоление которой затрачиваются значительные усилия и финансовые средства. Цель статьи – ретроспективно рассмотреть морфодинамику севастопольских бухт под воздействием хозяйственной деятельности. Использовались материалы наблюдений МГИ РАН, космические и аэрофотоснимки, литературные источники, а также массив карт и планов, главным образом XIX в. Показано, что в результате антропогенной деятельности природная среда севастопольских бухт существенно изменилась. Наибольшее воздействие на морфодинамику отмечается в районе Севастопольской бухты, где берега подверглись значительному антропогенному влиянию (срытие клифов, бетонирование береговой линии, строительство молов, пирсов и т. п.). Берега, которые можно отнести к непреобразованным, сохранились лишь на протяжении 1.1 км (3 % от первоначальной длины) береговой линии. Внешние берега бухт взморья в наибольшей степени сохранили природное состояние. Антропогенному воздействию, выразившемуся в срезке и планировании клифов, а также устройстве берегозащитных и пляжеудерживающих сооружений, подверглось только 1.3 км (17 %) береговой линии. Значительно большее воздействие испытали берега бухт взморья. Только в одной из них сохраняется средний уровень техногенной нагрузки, в трех он максимальный, а в трех – экстремальный. Из 33.5 км внутреннего периметра бухт относительно неизмененными остаются около 10 км (30 %). К настоящему времени в рассматриваемом регионе от ранее существовавших берегов с песчаными пляжами осталось только 0.3 км, или 10 %. Отмечается, что в результате антропогенной деятельности почти уничтожена Севастопольская группа соленых озер, ранее использовавшаяся в лечебных целях.

Ключевые слова: Черное море, севастопольские бухты, морфодинамика, антропогенное воздействие, береговая линия, соленые озера, аккумулятивные берега, абразионные берега

Благодарности : работа выполнена в рамках выполнения государственного задания FNNN-2021-0005.

Для цитирования: *Ефремова Т. В., Горячкин Ю. Н.* Морфодинамика севастопольских бухт под воздействием антропогенной деятельности // Экологическая безопасность прибрежной и шельфовой зон моря. 2023. № 1. С. 31-47. EDN THAAMX. doi:10.29039/2413-5577-2023-1-31-47

Introduction

Diverse and complex natural processes of various scales are constantly transforming the coast. At the same time, regional characteristics of the coastal zone determine various interactions and relative importance of individual natural processes. Human activity is another factor influencing coast transformation. It modifies natural environment and natural processes both directly and indirectly.

From the 20th century, the impact of the anthropogenic factor has increased so much that in some areas it significantly exceeded even the impact of natural processes. Urbanization, development of economy and communications, and the construction associated with them have changed natural landscapes of individual coasts beyond recognition, which, on the one hand, undoubtedly had a positive component, but on the other hand, led to a number of negative consequences. There are many such examples on the Black Sea coast [1–3].

Degradation of the coasts in the recreational areas of Crimea under the influence of the anthropogenic factor has become a serious problem, to overcome which significant efforts and financial resources are spent. Thus, the Southern coast of Crimea has almost completely lost its original coastal landscapes due to cost protection measures. In some parts of the coast, valuable accumulative beaches have disappeared either partially or completely (Evpatoria, Nikolaevka, Peschanoe village). The anthropogenic impact on the Crimean coast is considered in detail in [4].

A complete bibliography on the problems of studying the coastal zone of Crimea, available on the website of the library of the Federal Research Center "Marine Hydrophysical Institute of the Russian Academy of Sciences", contains almost no works devoted to the Sevastopol region. As a rule, it is mentioned among others, and there is not much information about it. This is quite understandable, since there was a base of the USSR Navy in the region for a long time, which limited publication possibilities. After the collapse of the USSR, hardly any research was carried out for a long time, and it was actually resumed 15 years ago. The purpose of the article is to retrospectively consider the morphodynamics of Sevastopol bays under the influence of anthropogenic activity.

Materials and methods of research

The materials of the MHI RAS observations, space and aerial photographs, literary sources, as well as a range of maps and plans (mainly of the 19th century) stored in the Sevastopol Maritime Library were used in the work.

Results and discussion

In the region under consideration, two areas can be distinguished.

The first one is Sevastopol Bay itself, currently with a total length of about 7.5 km and a perimeter length of 31.9 km from the entrance artificial piers (Fig. 1). The bay was formed due to flooding of the mouth of the Chernaya River during the post-glacial rise in sea level. The northern and southern shores of Sevastopol Bay, including Yuzhnaya Bay, were originally cliffs of Sarmatian limestone up to 30–80 feet (10–25 m) high [5]. The coastal relief is indented by gullies, which continue into smaller bays and concavities of the coastline. Before development, the coast could be attributed to the abrasion ingressive ria type. The ria type of shore, characteristic only for this region of the Black Sea, was indicated in the well-known monograph by V.P. Zenkovich [1)].

[1)] Zenkovich, V.P., 1960. [*Morphology and Dynamics of the Soviet Coasts of the Black Sea*]. Vol. 2. Moscow: Izd-vo AN SSSR, 216 p. (in Russian).

Fig. 1. Space image of the bays of Sevastopol, the numbers indicate the areas considered in the text (https://www.google.com/intl/ru/earth/)

Due to its configuration, the bay is only exposed to waves from the western direction. Before the construction of entrance piers in the 1970s the width of the entrance to the bay was 1.2 km; after construction, it decreased to 0.4 km. As a result, at present, significant waves hardly penetrate into the bay, and abrasion of the few surviving sections of the cliff is almost zero, which is also facilitated by blocky heaps on the shoreline. According to our calculations, by 2022 the coasts, which, with some reservations, can be classified as untransformed, have survived only 1.1 km (3 % of the original length) of the coastline. Almost all of them are located on the northern side of the bay.

The coasts of the region since the beginning of the 19th century were subjected to significant anthropogenic impact – concreting of the coastline, construction of piers, etc. In addition, significant parts of the cliffs were completely demolished. Thus, in Yuzhnaya Bay on the Korabelnaya Storona in 1830–1840 during the construction of the Lazarevsky Admiralty, a whole mountain of rock with a volume of 200,000 m^3 was manually demolished. During the construction of forts protecting the city from the sea, cliffs were also removed. First of all, these are the areas of the modern Primorsky Boulevard (on the site of the largest fort that has not survived – the Nikolaevsky), Konstantinovsky, Mikhailovsky and Pavlovsky forts.

At present, the coast of Sevastopol Bay can be confidently attributed to anthropogenic. The length of the modern coastline occupied by hydrotechnical facilities is 37,700 m; the coefficient 1.18 introduced in [6] testifies to the extreme technogenic load.

The second region stretches sublatitudinally to the west from the southern entrance pier to Cape Chersonesus. In a straight line, this distance is 10.5 km, and along the perimeter of the bays, it is 41.1 km. This section of the coast, together with the southern part of Sevastopol Bay, forms the northern coast of the Herakleian Peninsula. The flooded mouths of long and deep gullies form seven main bays. The ratio of the length of these bays to their width at the mouth varies from 0.8 (Pesochnaya) to 5.5 (Streletskaya) (Table 1).

Table 1. Morphometric characteristics of Sevastopol bays

Bay	Length (km)	Width (km)	Length/Width
Sevastopol	7.5	1.2	6.3
Karantinnaya	1.3	0.6	2.4
Pesochnaya	0.3	0.4	0.8
Streletskaya	2.2	0.4	5.5
Kruglaya	1.3	0.6	2.2
Abramova	0.8	0.6	1.3
Kamyshovaya	2.5	0.9	2.8
Kazachya	3.0	1.1	2.7

The shores between the bays are represented by an abrasion cliff composed of layered Sarmatian limestones, its height successively decreases from 25 m in the east to wedging out at Cape Chersonesus. Here on the shore, there is a shaft of large unrounded limestone fragments up to 1 m high. The foot of the cliff is bordered by a bench, on the edge there are heaps of blocks of large limestone fragments. In the concavities of the coast there are narrow (5–7 m wide) beaches made of boulders and large pebbles. The cliffs have wave-cut niches, which to the greatest extent intensify natural destruction of the coast (under the influence of precipitation, eolian and chemical processes, etc.) in the form of landslides. Therefore, the rate of cliff abrasion can only be estimated approximately, on large time scales. The average rate of coastal retreat, calculated from the data of repeated topographic surveys of the Chersonesus site over the past century, was 2.3–2.5 m [7]. The sector of active wave action on this region lies in a narrow range from west to north. Even with a relatively small acceleration of the waves, storm waves often develop here.

Recreational beaches on the open coast are artificial pebble beaches of the Pobedy Park, the Aquamarine Complex and the Cadet School on the watershed of Kruglaya and Streletskaya bays. The material of the beaches is quite successfully held with the help of the bun system. The outer shores of the second region have preserved their natural state to the greatest extent. Only 1.3 km (17 %) from the 7.6 km of the outer coast underwent anthropogenic transformation.

Table 2. Morphometric characteristics of Sevastopol bays and technogenic impact coefficients

Bay	Coast length (m)	Linear dimensions of hydrotechnical structures (m)	Technogenic impact coefficient (K)
Karantinnaya	3700	1775	0.47
Pesochnaya	1029	1087	1.05
Streletskaya	6007	3264	0.54
Kruglaya	3466	3312	0.95
Abramova	2370	1637	0.69
Kamyshovaya	7280	8640	1.18
Kazachya	9670	3577	0.37

Almost all of these sites are located between Kruglaya and Streletskaya bays. The anthropogenic impact here was expressed in the cutting and planning of cliffs, construction of coast-protection and beach-retaining structures.

The spaces of the bays themselves have undergone significantly greater anthropogenic impact, and this impact is constantly increasing. As can be seen from Table 2, only in Kazachya Bay the average level of technogenic load is preserved; in three bays it is extreme (Pesochnaya, Abramova and Kamyshovaya bays); in the rest – it is maximum. About 10 km (30 %) of the 33.5 km of the inner perimeter of the bays remain relatively unchanged.

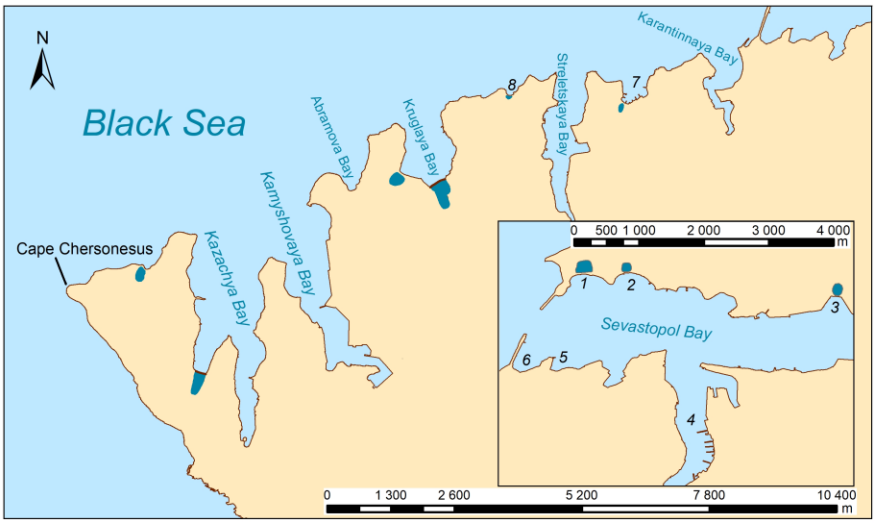
In the mouths of the bays, the movement of sediments is directed towards the apex, most pronounced in relatively shallow bays with a wide mouth (see Table 1), in the apex of which accumulative forms were created. At the foot of the cliffs adjacent to the outer side of the bays, there are narrow (up to 5 m) beaches made of poorly rounded limestone fragments. Sandy fractions are characteristic mainly of the apex parts of the bays.

In the region under consideration, accumulative forms occupied insignificant sections of the coast, and almost nothing was said about them in scientific literature. Meanwhile, there were bay-bars that separated the sea from salt lakes. At present, it can be said that under the influence of man, the lakes and, accordingly, the bay-bars have disappeared as a landscape and landform.

In Crimea, there are four groups of salt lakes – Kerch, Tarkhankut, Evpatoria and Perekop [2)]. From time immemorial, salt was mined here and at the end of the 19th century Crimean lakes provided 40 % of Russia's total salt production. From the 20th century, the therapeutic mud of the Evpatoria group of lakes has been used for medical purposes and brine has been used as a raw material for the chemical industry (production of bromine, magnesium oxide, etc.). From the 1930s such production was also deployed at the Perekop group of lakes.

Salt lakes of Crimea, depending on the characteristics of alimentation (sea, surface or groundwater runoff), are usually divided into two groups: *continental*, with a predominance of surface or groundwater runoff, and *marine*, the alimentation of which, in addition to surface and groundwater runoff, includes the sea [2)]. In this group, two subgroups are distinguished, one of which includes estuaries and bays that have retained communication with the sea. The second group includes lakes separated from the sea by solid barriers through which relatively weak filtration of sea water takes place. In addition, sea water in stormy weather can break through bay-bars. This subgroup covers most of the Crimean lakes, as well as the salt lakes of the Sevastopol group considered below, which were not included in any classification. This is due to the fact that now there is only one lake left out of at least nine that existed before (Fig. 2). For comparison, there are 14 lakes in the Evpatoria group, and 10 in the Kerch group.

The salt lakes of the Sevastopol region are mentioned in [8], where the Chersonesus group of lakes is distinguished, but by the time this work was published, the lakes indicated in it had not existed for a long time, some of these lakes were briefly mentioned by V.P. Zenkovich in his work [1)].



F i g . 2 . Locations of salt lakes in the bays of Sevastopol

[2)] Ponizovsky, A.M., 1965. [*Salt Resources of Crimea*]. Simferopol: Izd-vo "Krym", 162 p. (in Russian).

F i g . 3 . A fragment of a map of the coast of the northern side of Sevastopol: *above* – on the first map by navigator Baturin (1773); *below* – on the map by navigator Radionov (1840). The arrows show the lakes

There were three lakes in the first region: two in the lowlands on both sides of the watershed between the Konstantinovsky and the Mikhailovsky forts, Konstantinovskaya and Matyushenko bays (numbers *1* and *2* in Fig. 2); the third was located in the Panayotovaya Gully (number *3* in Fig. 2). These lakes are marked on the first map of Sevastopol by navigator Baturin, 1773 (Fig. 3).

For the first time, the contours of the lakes were shown in detail on the map of 1840. The area of each of them was 30–40 thousand m^2, they existed until the First World War.

On the site of the lake in the Panayotovaya (now Dokovaya) Gully in 1915, the largest dry dock in the city was built. At the same time, a seaplane base was deployed on the site of the lake in Matyushenko Bay, now there is a wasteland, partially overgrown with reeds. The lake near the Konstantinovsky Fort was liquidated in the 1930s, at present there is a residential development here.

Small fragments of sandy beaches have been preserved on the site of the former bay-bars. It is obvious that alimentation of accumulative forms (bay-bars) and their formation in this area is associated with the existence of a vast sandbar in the area of the Northern Spit, which Pallas wrote about based on the results of a survey in 1793: "... there is a small sandbank in front of the Northern Spit" [5, p. 37]. The author of [9], noting a swell-like elevation 1–2 m high elongated from north to south to the west of the entrance piers to Sevastopol Bay, makes an assumption that these are the remains of a bay-bar at the entrance to the bay, formed when the coast was lower than modern marks, when the estuary of the Chernaya River was a coastal salt lake.

On the first map of Sevastopol mentioned above, a continuous strip of sand is marked along the coast from the Northern Spit to Matyushenko Bay (Fig. 3). It is interesting that a comparison of maps for different years shows that at present the area of the sandbar has increased, while the depths in it have decreased, which can be associated with the construction in the 1970s of a 250 m long northern pier near the Konstantinovsky Fort, which interrupted the alongshore sediment flow. It is appropriate to note here that after construction of the southern pier 500 m long, the sediment inflow into Severnaya Bay completely stopped, and the water exchange, according to some estimates, decreased by a factor of three [10]. It can be seen from the analysis of old maps that earlier accumulative forms in the shape of sandbars were present in Yuzhnaya, Aleksandrovskaya, and Martynova bays (numbers *4*, *5*, *6* in Fig. 2). Now fragments of these forms have remained only in Aleksandrovskaya Bay.

In the second region, in the northern part of the Herakleian Peninsula, there were six lakes. One of them was located in Pesochnaya Bay (number *7* in Fig. 2). Its area was small – about 10,000 m^2. A mud bath was in operation on the basis of the silts of this lake in the late 19th – early 20th centuries. Like the bay-bars of the lakes of the Northern Side, the bay-bar in Pesochnaya Bay was composed of medium- and fine-grained sand, with the latter predominating. The bay-bar, unlike the lake, has survived to the present day in the form of Pesochny beach. However, its recreational properties are doubtful, because due to an erroneous design decision, crushed stone from a nearby artificial beach comes here. As a result, the beach contains both the original sandy material, which makes up the main body of the beach, and crushed stone, concentrated in the shoreline up to 15 m wide.

Two salt lakes were located in the southern and western parts of Kruglaya Bay; they were separated from the sea by two bay-bars [11]. Here is how they are described by Pallas: "Kruglaya Bay bears its name for a reason. It does not reach one verst in length and width and is no more than 6 sazhens (11 m) deep; it has a small islet inside with shallow depths of water around, and there are two salt lakes on the shore; one of them is separated from the bay in its depths only by a narrow bay-bar, and the other, on the western side, by a wider isthmus" [5, p. 41].

There was a mud bath that used the silt of the lake in the western part of the bay until the middle of the 19th century. According to an aerial photograph of 1942, the bay-bar in the southern part had a length of about 400 m, a width of up to 80 m, in the western part, respectively, 150 and 40 m. The area of the southern lake was about 80,000 m^2, and that of the western lake was 15,000 m^2. In the 1950s–1960s, the bay-bar of the southern lake was almost completely dismantled

into building sand, and the lake turned into a shallow (depth less than 0.5 m) apex part of the bay. Back in the middle of 1990s, a part of the bay-bar with the beach was preserved here. At the beginning of the 21st century, it was covered with soil where some apartments were built. As for the western lake, it is currently covered with construction debris, overgrown with reeds.

In place of the former bay-bar of the southern lake, the bottom topography now represents accumulative forms in the shape of underwater sandbars composed of sandy fractions. Starting from 2015, a new bay-bar has formed to the south of the pre-existing one; at present, its length is 45 m, and its width is about 25 m (Fig. 4).

The root part of the new spit is formed 400 m south of the previously existing one. This is due to the fact that a single alongshore sediment flow in the bay was interrupted due to the construction of three buns to the north, and the source of alimentation (sand poured onto the beach before the holiday season) is located to the south of them. The sand migrates to the inner part during storms. That is, we see the desire of the lithodynamic system of Kruglaya Bay (in the presence of alimentation sources) to return to its original equilibrium state. According to the sounding data, the depths are decreasing in the apex, where the base of a small fleet is located, i.e., the process of sediment accumulation continues. At the same time, the sediment flow in the bay itself is small, as evidenced by the apparent absence of sediment accumulation from the sea near the buns. The city authorities planned to fill up the apex of the bay. It was also planned to bury the remnants of the islet to improve navigation. These plans were based on an erroneous idea of the lithodynamics of the bay.

Fig. 4. The junction of the emerging sand spit on satellite images at the place of the former salt lake: *left* – 2009; *right* – 2020

F.i g . 5 . An islet in the center of Kruglaya Bay on the map of 1854 (*left*) [3] and 1856 [4] (*right*)

In the central part of the bay, there is an uplift of the bottom, which, during the period of the lowest stand of the level, protrudes above the water surface. Its length is about 150 m, its width is from 20 to 90 m. On ancient maps, this relief form was designated as a small islet (Fig. 5). By origin, it is, apparently, a remnant on which antique buildings were constructed. This was possible, since at that time the sea level was 2–3 m lower than today. This is indirectly confirmed by the presence of wave-cut niches in the western part of the bay at a depth of about 2 m, which we found during the survey of the bottom.

The underwater research in the bay was carried out by an expedition of the Department of Underwater Archeology of the Tauric Chersonesus Museum-Reserve [12, 13]. Some findings of artifacts made it possible to assume the existence of a public or religious building on the islet. On the southern side of the sandbar, using a diving survey and shooting from a quadrocopter, a rock fill about 60 m long and 20 m wide was revealed, the existence of which, presumably, was associated with the use of the bay water area as a harbor. Even 100 years ago, most of the bottom of the bay was covered with a sand layer and wide sandy beaches were formed

[3] Captain E. Lyons R.N., H.M.S, 1854. *Harbour of Sevastopol or Akhtiar, the antient Ctenus. From a Russian MS with additional soundings: map*. Scale: [circa 1:40,000]. G236:6/39. [London]: Hydrographic Office. 1 map; 57.5 × 34 cm.

[4] Lieut. Geo. R. Wilkinson, R.N. and Capt. T. Spratt, R.N.C.B., 1856. *Sevastopol, shewing the Russian defence works and the approaches of the allied armies*: *map*. Scale: 1 : 18,300. [London]: Hydrographic Office. 1 map: col.; 77 × 118 cm.

(survey by S. A. Zernov in 1912 [5]). To date, the amount of sand has significantly decreased due to its extraction, since the coast and the bottom are abraded under the influence of waves quite slowly due to the uplift in the center of the bay, which dampens the wave energy.

A significant salt lake existed in the apex of Kazachya Bay. According to [5], the length of the lake at the end of the 18th century was about 130 sazhens (238 m); a low bay-bar separating it was 60 sazhens long and 23 wide (110 and 49 m, respectively), of which 14 sazhens (26 m) was a flat white shore, apparently, flooded from time to time.

Further in [5, p. 41] it is noted: "In the salt lake, the bottom is as white as in the bay; the water level in it in the summer ... seemed much lower than in the bay." The area of the lake, apparently, was about 60,000 m^2. A dirt road ran along the bay-bar for many years. In the 1950s, most of the bay-bar, as in Kruglaya Bay, was dismantled for construction sand. At present, a small part of the spit in the eastern part of the bay has been preserved (Fig. 6). It is composed of sand with an admixture of rounded limestone fragments. Analysis of satellite images shows the current accumulation of sediments in the area of the former bay-bar.

Before the beginning of the 21st century, a small salt lake existed in the concavity of the coast at the site of the modern Aquamarine Complex (number *8* in Fig. 2). The area of the lake was about 1000 m^2, and the bay-bar was about 60 m long and 10 m wide. It was composed mainly of rounded limestone fragments. In 2010, the lake was filled in, and an embankment was built in its place.

Fig. 6. The remnant of the saline lake bay-bar in Kazachya Bay

[5] Zernov, S.A., 1913. [On Study of Life in the Black Sea]. *Zapiski Imperatorskoy Akademii Nauk po Fiziko-Matematicheskomu Otdeleniyu* [Transactions of the Imerial Academy of Sciences. Physical and Mathematical Department], 32(1), 280 p.

Finally, the only lake that has survived to this day is located near Cape Chersonesus. Here is how it is described in [5, p. 41]: "There is also a salt lake ... 60 sazhens (110 m – *Author's note*) in length on a shovel-shaped cape, which ends Crimea in the northwest. This lake also, apparently, was part of the bay, and its bay-bar was formed by the run-up of waves that carried silt and gravel into a dam of 60 sazhens in length and about 20 in width, one height with the shore; everything is surrounded by fragments of stones, like a small rampart, so that now salt settles in this lake, separated from the sea, which, however, does not happen every year. This salt, although of poor quality because [the lake] is saturated with bitter salt, is used and taken by the Tatars from neighboring mountain villages, who are forced to take the tenth load to the owner in Akhtiar for free; the same is done with regard to the lakes of Kruglaya Bay. Several salt flats, almost dry, visible on this cape at a distance of 60 sazhens from the lighthouse, apparently, are of the same origin and are separated from the sea by coastal, low drafts, like stone walls."

At present, the lake is double, in its southern, apex part there is one more bay-bar, both of them are composed of limestone fragments. The area of the lake is about 15,000 m^2, the bay-bar is 150 m long and up to 30 m wide. The landscape of the surrounding area is lacustrine-estuary with halophyte vegetation [14] (Fig. 7).

In 2016, the southern part of the lake was filled in during the road construction. Currently, the lake is in a regime zone and is not available for research. In general, it can be said that the bay-bars of the second region were formed in relatively wide and open bays with a shallow depth, where significant waves can reach their apex parts. In other bays, the movement of sediments either created spits or filled in the concavities of the coastline.

F i g . 7 . The last remaining salt lake in the Sevastopol region

Thus, in the upper reaches of Kamyshovaya Bay, on its eastern shore, there was a small fringing accumulative form – Marfa Spit. In the post-war period, the sand composing it was used as building material. Judging by the old maps, a short gully was covered with sand on the western shore of the central part of Streletskaya Bay within a fairly short period in the 20th century. In ancient times, the gully in the central part of Karantinnaya Bay, which was the inner harbor of ancient Chersonesus, was also "covered with sand as a result of the movement of marine sediments" [15, p. 8].

According to our calculations, the bay-bars of the lakes with sandy beaches previously occupied about 1.1 km of the coastline in the first region, 1.5 km in the second region, and 2.6 km in total. This is not much in relation to the total length of the coast, but by now only 0.3 km (10 %) of the coast with a sandy beach remains.

The estuary part of the Chernaya River, flowing into Sevastopol Bay, has undergone significant transformations under the influence of anthropogenic activity. In the post-glacial period, thick marine, firth-marine and alluvial deposits formed in the sea mouth of the river. In the middle of the 19th century, the mouth of the river was a swampy area – a river delta with numerous branches. It can be seen on old maps that there was a wide bar with depths of up to 1 m on the bank of the river. An even older inner river delta, the remains of which can still be traced, was located in the area of the modern bridge. Probably, the mouth section of the river and the Inkerman estuary were flooded by the sea during the next transgression, then, as a result of filling with sediments and regression of the sea, the marine stage of development of the mouth was replaced by the estuary, and later by the river development, and the mouth acquired modern relief [16]. At present, a deep water area is located on the site of the swampy delta. The configuration of the shores has been anthropogenically changed by the construction of piers, moorings, dams and other hydraulic structures on bulk soils. The main transformations of the mouth of the Chernaya River included construction of a bucket for the Sevastopol Seaport (in Inkerman), creation of an artificial reservoir with an area of about 0.4 km^2 at the mouth section of the river and the site of a floodplain swamp, and digging of a navigable canal (Fig. 8). Now the territory is a continuous industrial zone. In recent years, illegal sand mining has been carried out under the guise of leveling the coastline.

Significant swampy areas at the confluence of temporary watercourses were previously located in the apex parts of Yuzhnaya and Artilleriyskaya bays. Back in the 19th century, they were covered with soil excavated during cliff removal: in Yuzhnaya Bay during the construction of the Lazarevsky Admiralty (see above), in Artilleriyskaya Bay during the construction of the Nikolaevsky Fort. In place of the former swamp in Yuzhnaya Bay, there is now a railway station and a bus station. Small swampy areas at the mouths of temporary streams are now preserved only in Streletskaya and Kazachya bays.

Fig. 8. The mouth of the Chernaya River: on 1773 map (*left*), on 2021 space image (*right*) (https://www.google.com/intl/ru/earth/)

Conclusion

Based on the foregoing, the following main conclusions can be drawn:

1. as a result of anthropogenic activity, the natural environment of Sevastopol bays has changed significantly;

2. the greatest impact is noted in the area of Sevastopol Bay, where the shores have undergone significant anthropogenic changes: removal of cliffs, concreting of the coastline, construction of piers, etc. The shores, which can be classified as untransformed, have survived only for 1.1 km (or 3 % of the original length) of the coastline. The degree of technogenic load is extreme;

3. the outer shores of the coastal bays have preserved their natural state to the greatest extent. Only 1.3 km (17 %) of the 7.6 km of the coastline was subjected to anthropogenic impact, expressed in the cutting and planning of cliffs, installation of coast-protection and beach-retaining structures;

4. the shores of seaside bays have undergone significantly greater anthropogenic impact, and this impact is constantly increasing. Only in one of the bays an average level of technogenic load is preserved, in three bays it is extreme and in the remaining three it is maximum. About 10 km of the inner perimeter of the bays (30 %) of the 33.5 km remain relatively unchanged;

5. as a result of anthropogenic activity, the Sevastopol group of salt lakes, which were previously used for medicinal purposes, is almost destroyed. Only one lake of at least nine pre-existing lakes remains;

6. to date, in the region under consideration, only 0.3 km (10 %) of the previously existing coast with a sandy beach has remained;

7. significant transformations under the influence of anthropogenic activity are also noted in the estuary part of the Chernaya River and the swampy areas at the confluence of temporary watercourses, which were previously located in the apex of the bays, and in the 19th century were covered with soil excavated during cliff removal.

REFERENCES

1. Kuroki, K., Goda, Y., Panin, N., Stanica, A., Diaconeasa, D.I. and Babu, G., 2006. Beach Erosion and Coastal Protection Plan along the Southern Romanian Black Sea-shore. In: J. M. Smith, ed., 2006. *Coastal Engineering. Proceedings of the 30th International Conference, San Diego, California, USA, 3–8 September 2006*. World Scientific, pp. 3788–3799. doi:10.1142/9789812709554_0318
2. Nikolov, H., Trifonova, E., Cherneva, Zh., Ostrowski, R., Skaja, M. and Szmytkiewicz, M., 2006. Longshore Sediment Transport at Golden Sands (Bulgaria). *Oceanologia*, 48(3), pp. 413–432. Available at: https://www.iopan.gda.pl/oceanologia/483nikol.pdf [Accessed: 7 February 2023].
3. Stancheva, M., Marinski, J., Peychev, V., Palazov, A. and Stanchev, H., 2011. Long-Term Coastal Changes of Varna Bay Caused by Anthropogenic Influence. *Geo-Eco-Marina*, 17, pp. 33–40. doi:10.5281/zenodo.56892
4. Goryachkin, Yu.N. and Efremova, T.V., 2022. Anthropogenic Impact on the Lithodynamics of the Black Sea Coastal Zone of the Crimean Peninsula. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 6–30. doi:10.22449/2413-5577-2022-1-6-30
5. Pallas, P.S., 1999. [*Observations Made while Travelling along Southern Governorships of the Russian State in 1793-1794*]. Moscow: Nauka, 246 p. (in Russian).
6. Aibulatov, N.A. and Artyukhin, Yu.V., 1993. [*Geoecology of the Shelf and Coasts of the World Ocean*]. Saint Petersburg: Gidrometeoizdat, 304 p. (in Russian).
7. Lebedinski, V. and Pronina, J., 2014. Study of Ancient Coastline of Chersonesos and its Chora. *Khersonesskiy Sbornik*. Sevastopol. Issue 21, pp. 7–16 (in Russian).
8. Oliferov, A.N. and Timchenko, Z.V., 2005. [*Rivers and Lakes of Crimea*]. Simferopol: Dolya, 216 p. (in Russian).
9. Myslivets, V.I., 2017. Interrelationship of Man and Nature on the Coast of the South-Western Crimea. *Almanac Space and Time*, 14(1) (in Russian).
10. Ivanov, V.A., Ovsyany, E.I., Repetin, L.N., Romanov, A.S. and Ignatyeva, O.G., 2006. *Hydrological and Hydrochemical Regime of the Sebastopol Bay and its Changing under Influence of Climatic and Anthropogenic Factors*. Sevastopol: MHI NAS of Ukraine, 90 p. (in Russian).
11. Udovik, V.F., Kharitonova, L.V. and Goryachkin, Yu.N., 2017. Monitoring of the Urban Beaches of Sevastopol. *Ecological Safety of Coastal and Shelf Zones of Sea*, (4), pp. 86–94 (in Russian).
12. Bukatov, A.A., 2020. [Underwater Archaeological Studies in Kruglaya Bay]. *Problems of Underwater Archaeology*, (11), pp. 22–29 doi:10.24412/2220-0959-2020-11-22-29 (in Russian).
13. Bukatov, A.A., Bondarev, I.P. and Dyuzhenko, T.V., 2020. To the Question of the Existence of Chersonese Harbor in Round (Kruglaya) Bay. In: A. V. Zaikov, ed., 2020. *Khersonesskiy Sbornik*. Sevastopol. Issue 21, pp. 7–16 (in Russian).
14. Pankeeva, T.V. and Bondareva, L.V., 2014. Methodical Approaches to Landscape-Sozological Assessment of Coastal Systems. In: TNU, 2014. *Optimization and Protection of Ecosystems*. Simferopol: TNU. Iss. 11, pp. 57-67 (in Russian).
15. Bukatov, A.A., Bondarev, I.P. and Dyuzhenko, T.V., 2019. Tauric Chersonese Seaport in Quarantine Bay and Natural Processes. In: A. V. Zaikov, ed., 2019. *Khersonesskiy Sbornik*. Sevastopol: Albatros. Issue 20, pp. 7–20 (in Russian).
16. Minkovskaya, R.Ya. and Demidov, A.N., 2016. Evolution of Marine Mouth of the Chernaya River (Sevastopol Region). *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 81–88 (in Russian).

Submitted 24.11.2022; accepted after review 23.01.2023;
revised 1.02.2023; published 24.03.2023

About the authors:

Tatiana V. Efremova, Engineer, Marine Hydrophysical Institute of RAS (2 Kapitanskaya St., Sevastopol, 299011, Russian Federation), *efremova@mhi-ras.ru*

Yuri N. Goryachkin, Chief Research Associate, Marine Hydrophysical Institute of RAS (2 Kapitanskaya St., Sevastopol, 299011, Russian Federation), Dr.Sci. (Geogr.), **ORCID ID: 0000-0002-2807-201X, ResearcherID: I-3062-2015**, *yngor@mhi-ras.ru*

Contribution of the authors:

Tatiana V. Efremova – problem statement, data processing and analysis, article text preparation

Yuri N. Goryachkin – problem statement, data processing and analysis, article text and map preparation

All the authors have read and approved the final manuscript.