DOI: 10.22449/2413-5577-2022-1-6-30

Anthropogenic Impact on the Lithodynamics of the Black Sea Coastal Zone of the Crimean Peninsula

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

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

Abstract

The dynamics of the coastal zone of seas and oceans is contingent on a complex interaction of natural processes occurring at the border of land, sea, and atmosphere. This interaction has become even more complicated due to the anthropogenic factor. The purpose of the article is to systematize information about the anthropogenic impact on the lithodynamics of the Crimean coastal zone, classify the types of impacts and map them. The authors used materials of long-term monitoring performed by Marine Hydrophysical Institute of RAS. It is shown that the greatest influence on the change in lithodynamics is exerted by hydraulic engineering. Specific examples with quantitative characteristics are given. It is found that construction of permanent facilities on the beaches leads at least to their reduction and at most to their complete disappearance, which then results in increase of coast protection costs and reduces recreational properties of the coast. It is noted that the decrease in the solid runoff of rivers due to their regulation have influenced mainly the beaches of the Western Crimea. In the same place, 25 % of the total length of the cliffs is covered with various structures, and this has reduced the flow of sediments due to cliff destruction by 16,000 m^3 per year. The paper also discusses problems of degradation and disappearance of dunes, opening of bay-bars, reduction in the number of bottom molluscs, valves of which serve as a source material for the formation of sands, etc. The paper presents coefficients of anthropogenic load on various parts of the coast as well as maps localizing certain types of anthropogenic impact.

Keywords: Black Sea, coastal zone of Crimea, anthropogenic impact, lithodynamic, coast protection works

Acknowledgments: the work was carried out under state assignment no. 0555-2021-0005 of FSBSI FRC MHI RAS. The authors are grateful to V. V. Dolotov for his help with the map design.

For citation: 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

Антропогенное воздействие на литодинамику черноморского побережья Крымского полуострова

Ю. Н. Горячкин, Т. В. Ефремова*

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

Аннотация
Динамика береговой зоны морей и океанов обусловлена сложным взаимодействием природных процессов, происходящих на стыке суши, моря и атмосферы, которое еще больше усложнилось из-за антропогенного фактора. Цель статьи – систематизация сведений об антропогенном воздействии на литодинамику черноморского побережья Крыма, классификация видов воздействий и их картографирование. Использовались материалы многолетних мониторинговых наблюдений, выполняемых Морским гидрофизическим институтом РАН. Показано, что наибольшее влияние на изменение литодинамики Западного Крыма оказывает гидротехническое строительство. Приводятся конкретные примеры с количественными характеристиками. Установлено, что строительство капитальных сооружений на пляжах ведет как минимум к сокращению пляжей, как максимум – к их полному исчезновению, что в дальнейшем приводит к увеличению затрат на защиту берега и снижению его рекреационных свойств. Отмечается, что уменьшение твердого стока рек из-за их зарегулирования повлияло в основном на пляжи Западного Крыма. Там же различными сооружениями закрыто 25 % общей протяженности клифов, что снизило поступление наносов от разрушения клифов на 16 000 м^3 в год. Обсуждаются также проблемы, связанные с деградацией и исчезновением дюн, раскрытием пересыпей, сокращением количества донных моллюсков, створки которых служат исходным материалом для образования песков и др. Приводятся коэффициенты техногенной нагрузки на различные участки побережья и карты локализации отдельных видов антропогенного воздействия.

Ключевые слова: Черное море, береговая зона Крыма, антропогенное воздействие, литодинамика, берегозащитные сооружения

Благодарности: работа выполнена в рамках государственного задания ФГБУН ФИЦ МГИ № 0555-2021-0005. Авторы благодарят В. В. Долотова за помощь в оформлении карт.

Для цитирования: *Горячкин Ю. Н., Ефремова Т. В.* Антропогенное воздействие на литодинамику черноморского побережья Крымского полуострова // Экологическая безопасность прибрежной и шельфовой зон моря. 2022. № 1. С. 6–30. doi:10.22449/2413-5577-2022-1-6-30

Introduction

It is becoming more and more obvious that human intervention in the environment, while increasing the comfort of existence, simultaneously leads to significant problems now and creates prerequisites for their increase in the future. The most well-known problem is global warming due to the rapid increase in emissions of CO_2 and other greenhouse gases into the Earth's atmosphere, which is associated with the recent increase in extreme weather events [1]. Given that possible consequences, such as rising sea levels, coastal flooding, extreme heat, heavy rainfall, etc., affecting ecosystems and infrastructure around the world,

used to be the subject of many years of discussion in the scientific community, now many countries have moved to practical solutions that will seriously affect their economy and, possibly, their way of life in the future.

Many areas of waterways and territories on the planet have long been experiencing negative consequences of economic activity. This applies to a large extent to the coastal zone of seas and oceans, which is characterized by a complex interaction between natural processes occurring at the junction of land, sea and atmosphere. Recently, anthropogenic impact has been added to these processes. Human activity is currently comparable to geological forces, since in some areas it has been radically transforming the natural state of the environment [2]. For example, it is believed that more than 50 % of the coastline of developed countries (USA, Australia, Japan, Denmark, the Netherlands, etc.) has been changed by engineering structures [3].

Human intervention in the natural environment with negative consequences has many aspects, such as biological (for example, the impact of pollution on marine ecosystems and bioresources), economic (withdrawal of valuable land from circulation, destruction of coastal infrastructure) and others. In this paper, we consider one of these aspects - the anthropogenic impact on the lithodynamics of the coastal zone. The object of the study is the Black Sea coast of the Crimean Peninsula. The article focuses on Western Crimea, since this region is the most promising for recreational development, but is already experiencing certain problems associated with economic activity. The Southern coast of Crimea (SCC) is currently an almost completely urbanized area with extreme anthropogenic pressure, and the eastern coast, due to natural and social reasons, on the contrary, has not been affected much by economic activity.

The purpose of the article is to systematize information about the anthropogenic impact on the lithodynamics of the coastal zone of the Crimean Peninsula within the Black Sea, to classify the types of impact and to map them.

Publication analysis and state of the issue

In the Black Sea basin, where more than 300 million people live and about 20 cities with a population of more than 50,000 people each are located, the anthropogenic pressure on the coastal zone is increasing. It is due to urbanization and expansion of economic, especially recreational activities. In [4], we reviewed the literature dedicated to the anthropogenic impact on the lithodynamics of the Turkish, Romanian, and Bulgarian coasts. It was noted that, despite the difference in natural conditions, the sources of anthropogenic impact in these countries were the same: hydrotechnical construction, regulation of rivers by reservoirs, construction of permanent structures on beaches, illegal sand mining, dredging, etc. This impact changes the natural dynamics of sediments, creates their deficiency and destroys coastal ecosystems.

The influence of various types of hydraulic structures on the coastal zone of the Russian and Georgian coasts and the negative aspects of this influence were considered in [5, 6]. It was noted in [7, 8] that on the coast of Georgia, human

intervention in natural processes (removal of beach sediments, construction of dams, reservoirs, port facilities in the coastal zone) did not improve the economic condition of the country, and, together with current natural phenomena, provoked an increased trend towards coastal abrasion and disappearance of beaches. It also led to the threat of destruction of the infrastructure located there, which entailed huge material losses (several billion of US dollars).

The anthropogenic impact on the stability of the sea coasts of the Krasnodar Territory and the factors limiting their economic development are given in [9]. Among them, the most noted are reduction of solid runoff, destruction of sand dunes, removal of sand from the beaches, decrease in the volume of biogenic sediments (shells) entering the shores, and others. The negative impact of hydraulic structures on the adjacent areas of the coastal zone in the Ukrainian sector of the Black Sea was considered in [10]. Some aspects of the anthropogenic impact on the coast of Ukraine were given in [11].

The bibliography on the anthropogenic impact on the coastal zone of the Crimea is relatively small. Mostly, the articles cited individual facts of such an impact without a detailed analysis. Perhaps, V.P. Zenkovich was the first to draw attention to the problem of anthropogenic influence on lithodynamics in the Crimea. In an article devoted to the removal of beach material on the Caucasian coast and the negative consequences caused by this removal, he also mentioned the Crimea: "... such developments [of sand] are carried out even in Yalta, on the underwater slope of the Zheltyshevsky (now Primorsky – *the authors*) beach" [12, p. 54].

In response to this publication, a small article was published, which provided the facts of pebble material removal from the coastal zone of Yalta and its consequences [13]. The decrease in the width of the Livadia and Chukurlar beaches over the period of 5–7 years is determined as 22 and 65 cm, respectively, however, these values are less than the typical variability in the calm–storm cycle. Later, the same author noted that as a result of the extraction of 2 million m^3 of sand and gravel from the bottom of Yalta Bay, the width of the Chukurlar beach decreased over 12 years from 17.8 to 14.6 m, and the volume of the pebble beach decreased to 28 % [14]. It is not very clear from the text, whether it decreased by 28 % or to 28 % from the original, rather the former.

In [15], the changes in the material composition of sediments on the beach in Tikhaya Bay (Eastern Crimea, Koktebel region) were analyzed. According to the author, due to the introduction of the sea snail predator into the Black Sea, the number of bottom molluscs sharply decreased. If the share of mollusc shells in the composition of sediments used to be 8 %, in 1974 this value decreased to zero. The destruction of sand dunes was also observed due to the removal of their material for construction purposes, while the width of the beach decreased from 20–25 to 10–17 m (currently its width is 8–13 m – *the authors*). It was concluded (but without specific facts) that "a similar pattern of changes in the material composition and dynamics of sandy beaches was also noted to the west of Karadag in Chalka Bay, in the region of Evpatoriya and in some other places of the Crimea" [15, p. 103].

The values of coastal retreat as a result of functioning of a quarry for the extraction of gravel-sand mixtures in the area of the Saki bay-bar are given in a number of works [16–18]. In a series of works [19–21], which, however, differ little from each other textually and in the facts presented, the change of beaches in the area of Evpatoriya and the village of Privetnoye (Alushta region), data on changes in the width of beaches in Evpatoriya for 1995–1998 were given. The author of these works, not being a specialist in coastal processes, as he himself says, confuses the main and the secondary factors influencing lithodynamics. The main conclusion from his works is as follows: "... over the past half century, the main factor causing reduction of beaches is the anthropogenic factor – removal of sand and pebbles for construction purposes and unauthorized construction of various facilities in the coastal zone, as well as creation of reservoirs that trap sediments" [20, p. 63].

A detailed analysis of the anthropogenic impact on the beaches of the urban-type settlements of Koktebel and Kurortnoe (SCC, Karadag region) was carried out in [22]. The author proves that "artificial removal of sediments from the coastal zone and partial regulation of solid runoff led to a reduction in natural beaches and the need to create artificial beaches" [22, p. 86].

Separate facts of anthropogenic impact on the shores of the Crimean Peninsula are contained in our work [23]. In a brief review of the literature on the issue of anthropogenic impact on the lithodynamics of the Crimean coastal zone, we did not mention works that provide general reasoning without factual material, for example, [24]. Thus, it can be stated that at present there is no work generalizing the data on the technogenic load on the natural lithodynamics of the coastal zone of the Crimean Peninsula.

Materials and methods of research

We used the materials of long-term monitoring observations carried out by Marine Hydrophysical Institute of the Russian Academy of Sciences (echo sounding, georadar surveys, particle size analysis of sediments, tacheometric GPS surveys, measurements of wave currents, etc.). The data of aerial photographs and satellite images of ultra-high resolution, literary and archival sources were analyzed. The response of the coastal zone to the anthropogenic impact was identified as a change in the coastline configuration, appearance of previously non-existing areas of erosion or accumulation, change in the material and particle size distribution of sediments. In this work, we used the classification of types of anthropogenic impact, developed by us with some changes and clarifications [23, 25].

Results and discussion

In descending order of negative consequences on the coastal zone of the Crimean Peninsula, we have identified the following main types of anthropogenic impact: operation of hydraulic structures; permanent construction on the beaches; removal of inert materials from beaches and underwater coastal slope; reduction of solid runoff of rivers; clip closure,

dune destruction; artificial opening of embankments; change in the number of molluscs. Let us consider them in more detail.

Operation of hydraulic structures. According to their intended purpose, construction and operation of hydraulic structures should change natural processes. At the same time, positive consequences should prevail over negative ones, and the rationale for the need for these structures is also important. *Design of Marine Coast Protection Works* Rules (SP 277.1325800.2016) introduced in 2017 directly state that coast protection works must ensure only minimal disturbance of natural factors in the physical and environmental aspects in the present and future and must not reduce the aesthetic value of the coast. Not only must the achievement of the goal in the protected area be taken into account, but also the impact of these works on the adjacent sections of the coast. Typical solutions that do not consider specific natural conditions of the coast are unacceptable.

The high degree of anthropogenic pressure on SCC has already been noted above. To date, almost the entire coast, with the exception of hard-to-reach areas, is filled with concrete structures, more than 600 groins have been built. The technogenic load factor $K = l/L$ (where l is the linear dimensions of structures; L is the coast length) on the coast between Cape Sarych and Alushta (about 75 km) is 1.2, which is an extreme value according to the classification given in [26]. Undoubtedly, coast protection works built in the 1970s–1980s of the last century reduced the risk of landslide, expanded the areas of beaches and adjacent territories, but also created problems [27].

Thus, the moving material of artificial beaches almost completely destroys bottom biocenosis; stagnation and pollution occur in the space between the groins; the productive area is partially restored only on concrete surfaces [28]. As a result, the coastal water area of the SCC has lost valuable species of flora and fauna. It is significant that the concrete shore with typical groins for many kilometers worsened the perception of the unique nature of the SCC, especially since a significant part of the structures are either in an emergency or in a pre-emergency state (Fig. 1). Development of any free plot of land and an exorbitant anthropogenic load are already leading to the loss of attractiveness of the SCC as a resort.

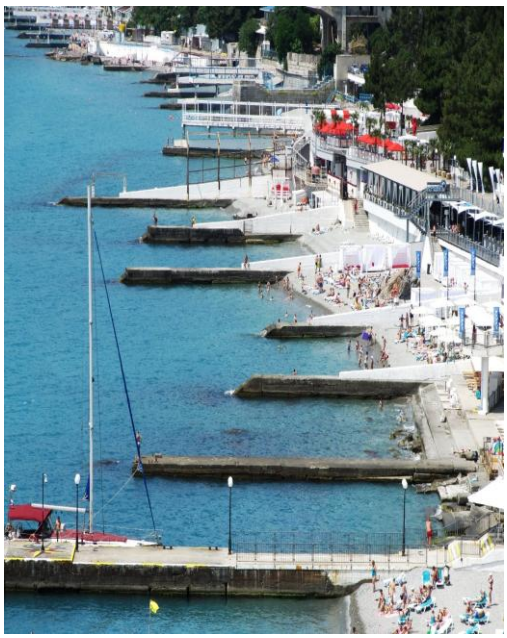


Fig. 1. Anthropogenic coast on the SCC

It is not surprising that vacationers and investors are increasingly paying attention to the coast of Western Crimea, where the anthropogenic load is still not so great (Fig. 2). At the same time, it is important to avoid the mistakes that were made here earlier, in the 1970s–1990s. They were caused by the desire to ennoble the coast with artificial structures using standard solutions that had already been tested in the SCC but did not take into account fundamentally different features of the lithodynamics of the coastal zone of Western Crimea. In fairness, it should be noted that incomplete implementation of design decisions also played a role.

Before human intervention, a feature of the lithodynamics of the coast from Evpatoriya to Sevastopol was an almost uniform alongshore sediment flow directed counterclockwise, which was first noted in [29]. The main source of sediments is abrasion of cliffs and benches. Due to the degree of river control (Belbek, Kacha, Alma), the solid runoff is extremely small. As a result of the construction of transverse beach-retaining structures (groins), the coast has turned out to be divided into a number of separate lithodynamic cells that hardly exchange sediments.

A typical example is the district of the urban-type settlement of Nikolaevka. By the end of the 1970s due to the almost complete cessation of the solid runoff of the river Alma beaches in the northern part of the settlement began to decrease, abrasion of the cliff intensified, threatening the buildings of recreation centers. Vertical walls were built twice, but they were destroyed by storms; later, two groins were built in the area of the nameless cape. They made it possible to build up the beach to the south to a width of 25–35 m (now its width is 10–15 m). However, to the north of the groin (near the complex of recreational facilities), the beach completely disappeared for about 700 m.

At the same time, during the 1980s the construction of slope-stepped embankments was carried out, which also captured the territory of the natural beach. Immediately after the construction, the beaches (whose width was 20 m) began to shrink, by 1999 their width became 2 m. In the absence of a beach, the embankment began to collapse rapidly.

At the beginning of the 21st century, on the southern section, six transverse groins were built in order to protect the sections of embankments that had survived by that time. Implementation of this project caused a significant restructuring of lithodynamics, further degradation of beaches and destruction of coast protection. Without giving all the details of the beach degradation in the settlement of Nikolaevka, which were set out in [30], one should note that now the beaches in many places are a heap of the remains of structures and are closed. Officially, more than 1 km of beaches have been taken out of use. There is a project to restore them, which is worth more than 10 billion rubles. Huge costs of various coast protection measures over the past years largely exceed the costs of low-value buildings on the cliff, which once should have been demolished.

The situation developed similarly in the resort settlement of Peschanoe, located at the mouth of the river Alma. Here the resort zone construction was started in the 1970s without taking into account the state of the main recreational factor – the beach, which by that time had already begun to degrade due to almost

Fig. 2. Negative effect on lithodynamics of the coastal zone (slightly transformed dunes – orange lines, significantly transformed dunes – purple lines, destroyed dunes – red lines); circles – sand extraction on an industrial scale; black spots denote permanent facilities on the beaches

complete cessation of the solid runoff of the river Alma. A beautiful sandy beach, more than 30 m wide, disappeared almost completely by 1982, abrasion of the cliff increased sharply, and a threat to coastal buildings was created.

At first the coast was unsuccessfully protected with vertical walls, and in the 1980s construction of slope-stepped embankments and 15 groins began, which was completed by 1990. After that, the beaches began to shrink, and by 1997 there was no beach in front of the embankment for 200 m.

From the same time, the process of destruction of coast protection works began, which soon became irreversible. The embankment, 1.3 km long, was completely destroyed by 2010. Some of the destroyed structures were subsequently dismantled (for more detail, see [30]). As a result, more than 1 km of the former beach is currently unused (Fig. 3). On most of the remaining beaches (about 2 km), natural sand and pebble beaches are replaced by artificial boulder and gravel beaches.

A typical example of an ill-conceived approach to the recreational development of the coast is the history of construction of a slope-stepped embankment in the village of Beregovoye at the mouth of the river Western Bulganak in 1985–1989, which was caused by the desire to civilize the coast (for more detail, see [30]). Here one can note that before the construction, the width of the pebble-sand beach was from 20 to 25 m. After the construction was completed, the beach began to decrease, by 2006 its maximum width in front of the embankment was 5 m, after which the beach up to 2 m wide appeared and disappeared.

In 2011, the process of deformation of the embankment began, and it was gradually collapsing. In 2021, it was restored according to a new project, as a result of which an artificial beach only 90 m long appeared, backfilled with 60–80 mm crushed stone, under the cover of two groins. On the rest of the embankment (300 m), instead of the beach, a blocky riprap was filled, the discharge of water from the river during floods is provided directly onto the embankment. To the north of

Fig. 3. Part of the embankment in the village of Peschanoe

this structure, the width of the beach decreased from 15–20 m to 10 m, and the rate of cliff abrasion almost doubled.

Negative consequences of a much smaller scale (mainly accumulation and bottom erosion over a length of up to 100 m) were also noted in the system of groins and concrete embankments in the territory of Sevastopol (settlement of Andreevka, Lyubimovka and Uchkuevka microdistricts). The smaller scale can be explained by the peculiarities of the lithodynamics of the region, in particular, by the relatively thin and differently directed in time alongshore sediment flows. On the whole, these projects can be considered successful, they solved the main task - creation of new beach areas with minimal damage in places of receding landslide coasts [31].

Above, we considered hydraulic structures, the main purpose of which is to protect the coast in recreational areas. Another type is constructions for technical purposes only. An example is a water intake structure for a military facility on the northern border of the bay-bar of Lake Kyzyl-Yar, near the town of Saki, built in the early 1980s. On the south side, it is a solid L-shaped reinforced concrete pier extended into the sea and transverse to the shore, and on the northern side it is a straight pier. This structure intercepted the alongshore flow of sediments coming from the south, as a result of which, south of the structure, sediments began to accumulate and the coastline moved out over time for its entire length – 80 m. To the north, downstream erosion began with intensive retreat of the coast; a significant part of the coast located downstream of the sediment flow was affected. As a result, by the end of the 1980s a section of the coast about 3 km long was recognized as emergency; and between 1983–2006 the average coastal retreat over 3 km amounted to 24–33 m.

To protect against the onset of the sea, the sanatoriums located here built coast protection works, including transverse structures (short groins), but the result was the same – build-up of the beach on the protected area and reduction of it on the neighboring ones. *Construction of a Pedestrian Embankment along Morskaya Street in the City of Saki* Project, which is currently being implemented here, initially provided for the construction of two 125 m long groins, although the authors of the article warned of possible consequences. However, at the construction stage of the groin, the bottom erosion and a change in the material composition of the beaches began, which forced the already implemented project to be sent for revision. This resulted in the expenditure of significant financial resources and delayed the implementation of the project by at least two years.

On the embankment of Lake Sasyk-Sivash (between the cities of Evpatoriya and Saki) since the mid-1960s, there is a now abandoned water intake structure to replenish the lake, the waters of which previously served as raw material for a now closed chemical plant. In terms of configuration and geometric dimensions, this structure is similar to the water intake structure described above, however, its construction did not lead to significant negative consequences. Long-term instrumental observations on two opposite sides of the water intake structure and analysis of satellite images show that there is no explicit unidirectional flow here. Depending on the direction of storms, on both sides of the structure, in antiphase,

accumulation or erosion is observed with an amplitude of changes in the coastline up to 10 m, which, as a rule, propagate at a distance of up to 50 m from the structure.

When designing port hydraulic structures, as the most expensive, the effect of a whole complex of factors for many years to come is taken into account. According to the master plan for the development of the city of Evpatoriya, adopted in 1948, it was supposed to make a single embankment about 4 km long from the park named after Frunze to the eastern outskirts of Evpatoriya by developing an empty site in the area of Karantinny Cape in the city center.

Instead, a port was built here in 1978. Sandy beaches were concreted, a pier 200 m long was built in the form of a monolithic concrete structure, the tip of which (70 m) was erected on piles. As a result, sediments began to accumulate near the western part of the pier, building up the beach. When the beach reached the end of the concrete part, during southwestern storms, sediments began to go around the continuous part of the pier, creating a shallow on the opposite side. This necessitated dredging, during which, according to the port, up to 150,000 m^3 of sand were removed annually. The beaches to the west of the pier, devoid of reverse flow, began to shrink rapidly. Comparison of aerial photographs from 1941 and 1947 with modern satellite images showed that in a 2.5 km long area, the area of beaches decreased by 52,000 m^2, and the average retreat of the coastline amounted to 20.8 m [32]. Previously, the beaches here were composed of pure yellow sand with a predominant particle size of 0.25 to 0.5 mm [33]. At present, due to the reduction in the vertical thickness of sandy deposits, the content of large pebbles and limestone boulders has sharply increased, especially in the waterfront zone. In some places, clay deposits are exposed after storms.

Interestingly, in the 20^{th} century transverse structures were built in Evpatoriya Bay at different times, while the nature of sediment accumulation unambiguously testified to their two-way alongshore movement with a clockwise direction predominating, which was not taken into account when designing the port [32]. Let us note that its construction was not economically justified both during the Soviet era, and more so now. The main activity of the port, which occupied a valuable seaside area of 6.4 hectares, was extraction of sand in the lake-bay Donuzlav (40 km from the port). For many years, they tried to transfer the Evpatoriya port to Donuzlav. There is currently a plan to convert it into a marina. Here it is appropriate to note that construction of Yalta Cargo Port was not economically justified either. Unfinished and almost not used for its intended purpose, the port has been in a partially destroyed state for 30 years after a severe storm in autumn of 1992.

Returning to Evpatoriya, it can be noted that together with the construction of the port, after the destruction of another embankment by storms (three of them were built in the 20^{th} century), a new one was erected in the central part of the city. To protect the shore, a 1.8 km long shaped wave barrier was erected, while the front of the embankment was set forward 30–50 m from the former

water edge. After the construction, the sandy beaches that had existed here before completely disappeared. If earlier the bottom of the western part of the bay was composed of yellow biogenic sand, later, according to the survey data of 2012, it was covered with gray-black silty sand and heavy growth of *Zostera marina*. Currently, the dilapidated embankment is being reconstructed together with an artificial pebble beach. Thus, in Evpatoriya, as a result of the construction of hydraulic structures, the beaches completely disappeared over 3 km and significantly decreased over 2.5 km. Locations of the coast protection works of the Crimea are shown in Fig. 4.

Permanent construction on the beaches (mainly of recreational facilities), despite legal prohibitions in the USSR, Ukraine and the Russian Federation, and its obvious negative impact on the coastal zone has been and remains a common practice. The objects are documented as coast protection works with rest rooms, fishing boxes, rescue stations, reading rooms, etc. A map presenting the location of the largest works is shown in Fig. 5. According to it, most of them are situated on the SCC, but there are enough of them in other resort areas. Let us give some more examples.

On the eastern outskirts of Evpatoriya, in the early 1960s, according to aerial photography, the width of sandy beaches was about 50 m. After the construction of the above-mentioned pier and concrete embankment in Evpatoriya, they began to shrink. Nevertheless, private individuals, whose houses were located behind the front of the beach, gradually erected various buildings on it, approaching the water edge. As a result of the change in the profile and width of the beaches, the wave action on the coast increased with its erosion. Soon this zone and adjacent parts of the coast were declared as being in the state of emergency. Attempts of the city authorities to resettle the houses proved unsuccessful.

F i g . 4 . Coast protection structures

F i g . 5 . Permanent facilities on beaches

The owners of the buildings began to independently strengthen the coast with walls, but the situation deteriorated significantly. The beach disappeared completely for about 1 km, and an unattractive artificial cliff of construction debris up to 2 m high appeared on the shore, presenting a danger to vacationers.

In the beam cut into the cliff to the north of the urban-type settlement of Nikolaevka, in 1989, residential buildings of the *Yakor Cooperative* were erected. By cutting off part of the cliff and fixing the coastline on the beach with concrete, the builders had not taken into account the fact that the coast was receding. As a result of this ill-conceived construction, serious problems arose in the coastal zone for many years. Over time, a cape formed on the site of the embankment, protruding 50 m from the natural configuration of the coast. As a result, the beach to the north disappeared and the cliff accelerated its retreat. Thus, only between 2004–2014 the coastline receded here by 15 m. It is known that wave energy increases on the capes, and this fact aggravates the situation even more. The buildings, which were located earlier in the rear part of the beach, later turned out to be on the water edge. During storms, waves throw stones at the windows of first-line apartments, and the embankment collapses.

In the urban-type settlement of Kacha in 2004–2012 a 400-meter long six-storey apartment complex named *Nash Parus* was built with an official name *Coast protection work with recreational facilities*. Part of it was built on the beach, another part – on the site of a cut cliff. Prior to construction, the average width of the sand and pebble beach was 15–20 m. As early as in the construction period, there was a change in the configuration of the water edge and a decrease in the width of the beach. At present, its width is 2–4 m (sometimes it is completely absent), which is accompanied by a sharp decrease in the volume of beach-forming material and an increase in the content of coarse sediment fractions.

When even moderate intensity storms take place, the beach undergoes wave processing along the entire width, as a result, the wave load on the structure increases. We noted underwashing of the foundation and destruction of the stairways to the sea, abrasion of elements of reinforced concrete structures and exposure of reinforcement. To the south of the apartment complex there is a complex of six-story buildings, the so-called boathouses, with a length of 270 m along the front of the coast. The buildings owned by private individuals are now almost at the water edge (now the width of the beach is 0 to 6 m, it used to be 20–30 m) and threaten people's safety.

In addition to construction on the beaches, a significant danger is construction of buildings on the edges of the cliffs, which is most typical for Sevastopol region: its northern shores are clayey, landslide-prone cliffs. During the Soviet period, only vegetable gardens were allowed here. After the collapse of the USSR, intensive development of these sites began for the construction of dachas and mini-hotels. As a result, about six linear kilometers have now been built up, which has led to the activation of landslides and destruction of buildings. This situation is due to the increased load on landslides by buildings, soaking and weighting of slopes due to irrigation, water leaks and lack of sewerage.

Thus, a huge *Bay of Dreams* hotel, built on the edge in the preserved natural landmark of Laspi Bay on the SCC has forever changed the picturesque landscape. In addition, its construction was carried out on the territory of the development of landslides and tectonic faults. Storms repeatedly eroded the stone filling in front of the hotel's facade, smashed the reinforced concrete wave-breaking wall into separate fragments, and deformed the embankment and boathouses.

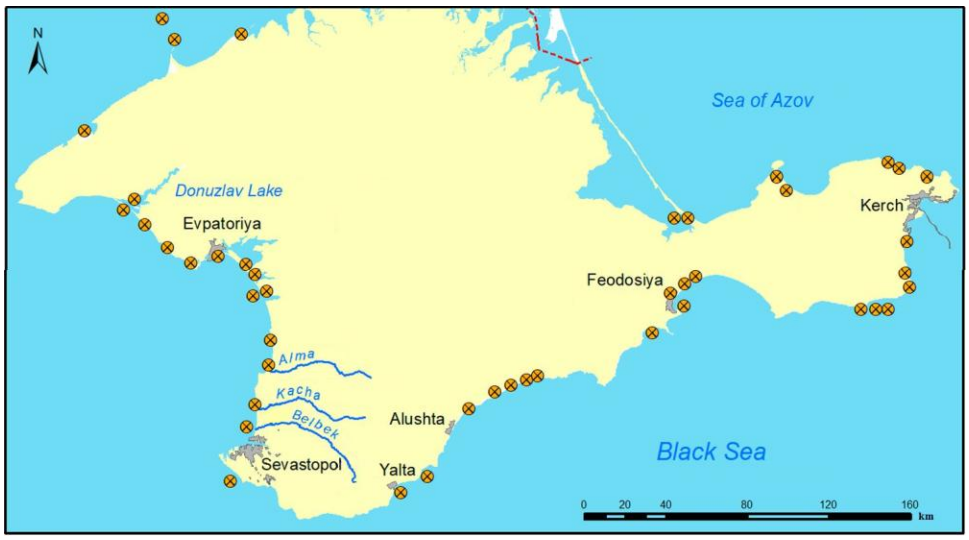
Removal of inert materials from beaches and underwater coastal slopes on a small scale has always been carried out for local construction. For a long time, this was not considered something reprehensible. The Evpatoriya City Duma, discussing such removal on the beaches of the eastern outskirts of the city, in a decree of 1887 allowed such activities, imposing a tax on them. Economic growth and urbanization in the 20th century resulted in the need of a large number of inert materials (sand, gravel, pebbles) for the construction industry. In Crimea, the period of their industrial extraction from the coastal zone began in the 1930s; the sand from the Saki bay-bar area was used for the construction of the Dnieper Hydroelectric Station (the sand was of good quality); up to 1000 m^3 of sand was mined per day. Mining here reached its real scale in the post-war period. The sand was not only used for construction in the Crimea, but was also exported by rail and sea to Odessa and other ports. Barriers separating the quarries from the sea narrowed under the influence of storms and arched towards the quarries. At the same time, a reduction of beaches up to 100 m was noted in places adjacent to the quarries. In a survey carried out by a special commission in 1962, it was noted that further mining of sand and gravel should be stopped. Due to the real danger of changing the salinity of the brine in the healing lake and the threat to the famous mud, the quarries were closed, and the sand extraction continued by refilling it from the bottom of the sea. However, the situation

continued to deteriorate, after which sand mining was soon completely stopped. Instead of sand dunes, salt lakes and so-called droughts (wetlands) have formed at the site of sand mining, which still exist today.

Even in the middle of the 20th century in Koktebel (Eastern Crimea) there was a sand-gravel-pebble beach 20–30 m wide. It was distinguished by an unusual color due to inclusion of pebbles from the Karadag rocks. Semi-precious stones from the beaches were a welcome souvenir for vacationers. Beach deposits were developed unprofessionally for local construction needs in relatively small volumes. However, in 1954, commercial extraction of sand and gravel mixtures began in the central part of the bay. It was also carried out in neighboring areas near the urban-type settlements of Kurortnoe and Ordzhonikidze, as well as Tikhaya Bay. Large volumes of mixtures were exported, including for the construction of various strategic facilities. The data on actual production volumes are not available, but it is known that it continued until 1967.

As a result, the beaches began to shrink rapidly, and by the mid-1960s their width in the western part of the bay was already 5–10 m, which led to the destruction of the embankment by storm waves [35]. The rapid reduction of the beaches forced the construction of expensive coast protection works, creating artificial beaches with a much worse material composition compared to the natural ones in Koktebel and Kurortnoe. Subsequently, the construction of permanent structures on the beaches in these settlements led to the second wave of beach disappearance. A project for their recovery is currently being developed.

A large area of extraction of sand and gravel mixtures from an underwater slope by suction dredgers in the 1950s–1960s was located in the northern part of Sevastopol, at the mouth of the Belbek and Kacha rivers, as well as in the area of the Uchkuevka beach. In the latter area, the impact of extraction was especially strong, resulting in a landslide of 1.5 km long. Until now, it remains the most active in the region, its catastrophic shifts periodically occur, destroying buildings on the edge of the head fall. In the region of the mouth of the river Kacha, the beach as a whole receded by 20–30 m, which was also affected by the river control. This affected the beaches near the mouth of the river Belbek to a lesser extent, since solid runoff has so far retained up to 80 % of the previously existing volume. Back in the late 1950s V.P. Zenkovich wrote: “Alluvial and beach material is taken in the lower reaches of the Belbek and Kacha rivers, but these removals are replenished during floods and, apparently, do not pose a danger to the stability of the coast” [29, p. 199]. However, in that era, the rivers were not controlled yet. Until the 1970s mining of inert materials was carried out almost everywhere (Fig. 6.), which led to severe consequences in the coastal zone. In this regard, the Decree of the Council of Ministers of the USSR No. 40 of January 17, 1969 “On urgent measures to protect the Black Sea coast from destruction and rational use of the territories of the resorts of the Black Sea coast” was issued, where, among other measures to reduce anthropogenic load on the shores, it was proposed “... to take measures to stop the use of pebbles and sand of the sea coastal strip for the needs of construction”.



F i g . 6 . Proved sites of extraction of inert materials on an industrial scale

In general, this decree was carried out. We know of only one example of illegal sand extraction from the bottom, which was carried out south of Sevastopol and in the area of the Bakalskaya Spit (north-western coast) in 2011–2012. As a result of numerous public protests, sand extraction was banned. After the Crimea was incorporated into the Russian Federation, the same company was issued a license for sand mining at the Bakalskaya Bank until 2019. Now, due to public protests, mining has also been stopped. In 2019, on the cliff of the northern side of Sevastopol, under the guise of creating a recreational zone, the extraction of gravel-pebble mixtures was arranged in two quarries, 165,000 m^3 was mined at a smaller one [36]. By the decision of the city authorities, this work has now been suspended. Currently, there is only one official underwater quarry, in the inner part of Lake Donuzlav, which has a minimal impact on the lithodynamics of the coastal zone of neighboring areas [37]. We are aware of recent attempts to license sand mining in the Crimea at several underwater deposits, but we do not know what decisions have been made. It should be noted that only in the Foros-Alushta section, reserves of 88 million tons have been explored at the bottom, which are classified as off-balance and attract the attention of builders.

Decrease in the solid runoff of rivers and temporary streams due to river control in the 1960s–1970s affected mainly the regions of Western Crimea. In 1964, in the upper reaches of the river Belbek, three reservoirs were built: Klyuchevskoye, Shchastlivoe-I and Shchastlivoe-II, and in 1975 Zagorskoye reservoir was built on the river Kacha. Besides, a whole cascade of storage ponds of a smaller scale was built. Due to the increase in the building area and other economic activities, the erosive washout in the river basins has also decreased. The flow of the river Western Bulganak has stopped completely. Unauthorized

sampling of material is carried out directly from the river bed. As a result, the volumes of solid sediments, especially coarse fractions that form beaches, have decreased. To the greatest extent the decrease in solid runoff affected accumulative beaches at the mouths of the Kacha and Alma rivers, as discussed above. Apparently, it had little effect on the beach at the mouth of the Belbek river, since it is the largest river of the Crimea that retained a significant amount of runoff. It should be noted that in 2021, a water intake structure was built 15 km from its mouth. The first six months of its operation showed that it accumulated solid deposits to a large extent. A recommendation was given to discard the obtained material in the mouth zone during its cleaning. It is currently believed that the volume of solid runoff of the Kacha river is 6.72 thousand m^3/year, or 12.1 thousand t/year, and of the Belbek river – 18.0 thousand m^3/year, or 32.4 thousand t/year [38]. This information is also given by the authors of later works, for example [39]. The given data give rise to certain doubts, since observations at the mouth of these rivers have not been carried out for a long time.

The closure of cliffs by various structures leads to a decrease in the inflow of sediments from the wave field into the coastal zone and, as a result, to a reduction in beaches. This factor is most important in Western Crimea. The existence of beaches depends primarily on the sediment reserves on the beach and the possibility of their continuous supply. The main source of sediment replenishment of the coastal zone of the region from the mouth of the river Belbek to Lake Kyzyl-Yar with a length of about 50 km are the products of the cliff destruction as a result of abrasion and landslide processes, namely, layers and lenses of alluvial pebbles and sand of the ancient river network. At different times, part of the cliffs was removed from the balance of sediment supply to the coastal zone as a result of the construction of coast protection works, creation of quarries, and terracing of slopes. The length of active cliffs within the city of Sevastopol from the mouth of the river Belbek to Cape Tubek is about 23 km. At present, according to our calculations, the length of the coast with the cliff closed or withdrawn from inflow into the coastal zone is 4.3 km, or 19 % of the total length. 8.5 km or 32 % of the cliffs are closed between Cape Tubek and Lake Kyzyl-Yar (about 26 km). In general, in Western Crimea, 25 % of the total length of cliffs is not a source of sediment. Our calculations showed that the average specific drift per linear meter per year is on average 1.27 m^3, which means that about 16,000 m^3 per year is removed from the input part of the sediment balance. This indicator is four times less than that given in [40]. Our estimate seems to be more reasonable, since it is based on specific data on the rate of abrasion over a long period and data on the structure of cliffs obtained from boreholes and geomorphological surveys.

Dune destruction is one of the factors of the negative anthropogenic impact on the coastal zone. It is known that coastal dunes are a natural accumulator of sand, a natural barrier that protects sandy shores from erosion. In addition, sand dunes on the coast are unique ecosystems with a rich diversity of plant communities; in some areas they play a significant role in the balance of sediments. Until recently, coastal dune landscapes occupied fairly large areas of the Crimean coast.

It is enough to look at old photographs of Evpatoriya and Feodosiya to make sure that the coastal parts were occupied by dunes. Their largest range was in Western Crimea.

Previously, the dunes were partially destroyed, reconfigured during extreme storms, and then gradually restored. However, in recent decades, human activity has become the most destructive factor. The anthropogenic impact on the dunes is caused by increased coastal urbanization and is expressed in the construction of various recreational facilities, roads, parking lots, unregulated campsites and 'temporary' buildings, planning the natural relief of the beaches. Since beaches in many places are composed, in addition to sand, of fragments of limestone gravel and boulders, sand blowing rather quickly leads to the appearance of ridges of this material on the beach surface (Fig. 7). The material composition of beaches is changing, their recreational properties are sharply deteriorating.

Besides, the dunes are often the site of illegal sand extraction. Destruction of vegetation cover, including by ATVs, which are increasingly used as a recreation element, leads to an increase in the eolian removal of sand from the beach to the sea and to the territory of recreational facilities. Traces of such removals, for example, in the urban-type settlement of Zaozernoe, are visible everywhere. Erection of tall buildings near the dunes prevents the return of sand blown from the coastal zone to the beach, which is another reason for the retreat of the coast.

Prior to the active development of the Black Sea coast of Crimea, the length of its coasts with a dune landscape, according to our estimates, was 94 km. At present, such shores have disappeared completely for about 14 km, and partially for 33 km. Their area continues to decrease (Fig. 8). Due to anthropogenic impact, the dune landscapes of the Crimea are currently under the threat of degradation or extinction. Their natural recovery is either very slow or impossible

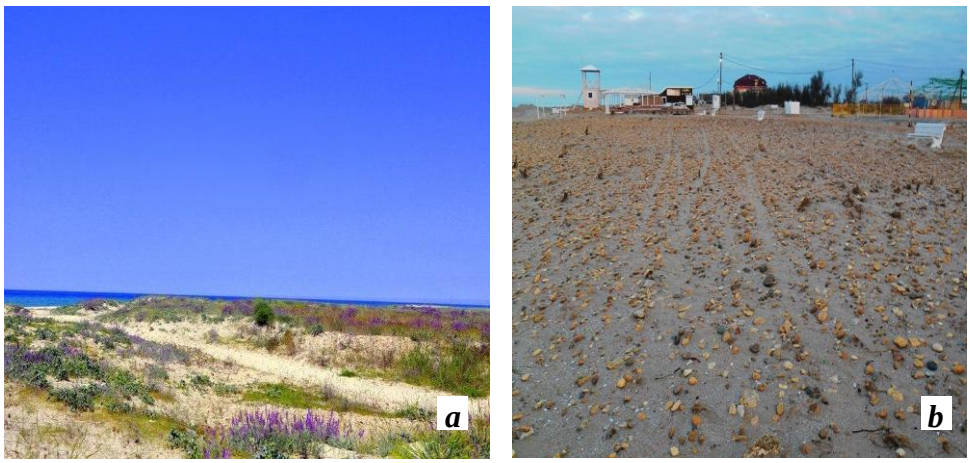


Fig. 7. Dunes before (*a*) and after (*b*) planning of the beach in the vil. of Shtormovoe

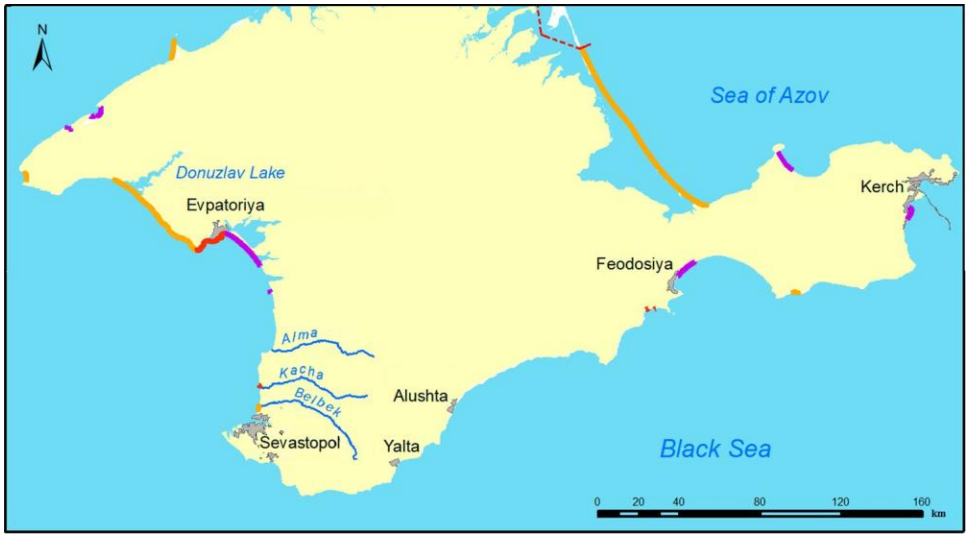


Fig. 8. Location of dunes (slightly transformed dunes – orange lines, considerably transformed dunes – purple lines, destroyed dunes – red lines)

at all, so they need protection and restoration. In December 2021, on the bay-bar of Lake Oyburskoye, where a large dune complex is located, a protected area was created instead of a shrimp farm thanks to the long-term struggle of local residents.

Artificial opening of bay-bars of salt lakes is still limited, although there are plans to use the lakes of Western Crimea for arranging yacht parking; there was also a plan to build a port on Lake Bogayly. The negative impact of bay-bars opening is reduction of the length of beaches and change of sediment dynamics in the adjacent areas. As a result, there is a need to build coast protection works. In the 1950s–1960s, in Western Crimea, bay-bars of Lake Panskoe (Sasyk) in Yarylgach Bay, Lake Donuzlav, Lake Oyburskoye (the bay-bar is currently closed), as well as bay-bars in Kruglaya and Kazachya Bays (Sevastopol) were discovered.

Immediately after digging of the canal in Lake Donuzlav in 1962, to determine changes in the lithodynamic regime, observations were organized over the dynamics of the coastline. After the completion of the canal during 1961–1966 the coastline in the areas adjacent to the canal receded by 25–60 m. In subsequent years, alternating changes in the coastline with its gradual leveling were observed. After two concrete spurs were built, by the 1980s the coast stabilized.

Until 1960s in the southern and western parts of Kruglaya Bay (Sevastopol), there were two sandy bay-bars separating salt lakes. Here, before the Crimean War (1854–1856), there was a mud bath of the military department, according to

some sources, it existed in ancient times. As evidenced by aerial photography in 1941, the sandy bay-bar in the southern part was about 400 m long and up to 80 m wide. In the post-war period, the bay-bar was almost completely demolished for construction sand, and the lake turned into a shallow (about 0.5 m) apex part of the bay, overgrown with marine vegetation. Back in the mid-1990s a part of the bay-bar with the beach was preserved here. At the beginning of the 21st century, the beach was destroyed, and apartments were built right on the edge under the guise of fishing boxes. Currently, a filling made of large boulders covered from above with construction debris has been made on the edge to protect the apartments.

Changes in the number of molluscs in the Black Sea have been recorded since the beginning of the 1960s. This fact is usually associated with the invasion of the Black Sea from the Pacific Ocean by the predatory mollusc *Rapana venosa*, which successfully adapted to new conditions and drastically reduced the populations of native molluscs, becoming the predominant species of benthic communities. The invader caused serious damage to oyster and mussel biocenoses, but now, due to undermining of its own food supply, the number of *Rapana venosa* has significantly decreased [41]. However, in some studies on the diet of *Rapana venosa*, it was noted that the oyster is not its preferred food object. In addition, in the northwest of the Black Sea, an outbreak of mortality among oysters began before the mass appearance of *Rapana venosa*, so the question of the influence of the latter on the populations of oysters in the Black Sea is still debatable [42].

In addition, the dynamics of the number of molluscs, obviously, was also affected by anthropogenic pollution of the water area and bottom sediments of the coastal zone by municipal and industrial wastewater. Together, these factors led to a decrease in the number of bottom plant communities that fix the soil, as well as to a decrease in the number of molluscs, the valves of which serve as the source material for the formation of sands. At the deep coasts, this does not actually have any noticeable effect on the sediment volume.

At one time, observations of the process of changing the number of molluscs were not arranged, so there are few publications on this topic. One of them analyzes changes in the taxonomic composition of benthic biocenoses of the Crimean coast [43]. In another, it is noted that compared with the 1940s the mass of zoobenthos decreased by more than eight times [44]. In general, this factor acts as a background factor and is important for the shallow water areas of Western and partly Eastern Crimea.

We have considered the main types of anthropogenic impact on the lithodynamics of the Black Sea coastal zone. In addition to those noted above, one can also indicate unprofessional coast protection in the form of backfilling various materials (up to construction debris) into the waterfront zone, digging trenches parallel to the coast on the beaches or collecting sand in shafts for the winter period, installing concrete slabs on beaches, etc. The degree of technogenic load for various areas of the Black Sea coast of Crimea is shown in the Table. It can be seen that the maximum load is typical for Sevastopol and the SCC.

Anthropogenic load (*K*) for various districts of the Black sea coast of Crimea

Coastal area	*K*	Load degree according to [26]
vil. Portovoe – Evpatoriya	0.02	minimal
Evpatoriya – Sevatopol	0.28	average
Sevastopol	1.18	extreme
Cape Chersonesos – Cape Sarych	0.02	minimal
Cape Sarych – Alushta	1.21	extreme
Alushta – vil. Morskoye	0.60	maximal
vil. Morskoye – Feodosiya	0.05	minimal
Feodosiya – Cape Takil	0.03	minimal

Conclusion

Based on the above, the following conclusions can be drawn. Hydrotechnical construction has the greatest impact on the change in the lithodynamics of the Crimean coastal zone. The construction of transverse hydraulic structures (groins) on the coastal slope in Western Crimea blocked the natural alongshore flow and broke it into separate lithodynamic cells. The consequences manifested themselves in the form of bottom erosion, covering significant parts of the coast.

Despite the previous negative experience, the design and construction of such structures continues. The construction of permanent facilities on beaches leads to at least a reduction in the number of them, and at the most to their complete disappearance, which in the future requires expenses to protect the coast and reduces its recreational properties. The greatest damage is inflicted in the zone immediately adjacent to permanent structures.

The previously carried out selection of inert materials from the beaches and the underwater coastal slope of the Crimean coast required significant material costs for restoration of degraded or vanished beaches.

The decrease in the solid runoff of rivers and temporary watercourses due to their control mainly affected the regions of Western Crimea, while to the greatest extent it affected accumulative beaches at the mouths of the Kacha and Alma rivers.

The closure of cliffs by various structures leads to a decrease in the flow of sediments from the wave field into the coastal zone and, as a result, to a reduction of beaches. This factor is most important in Western Crimea, where 25 % of

the total length of the cliffs is not a source of sediments; about 16,000 m^3 per year is removed from the incoming part of the sediment balance.

On the Crimean Peninsula, before the start of its active development, the length of the coast with dune landscape was 94 km. Due to anthropogenic impact, the dunes are under the threat of degradation or extinction, for about half of their length they have already completely disappeared or degraded and their area continues to shrink.

The negative impact of the opening of bay-bars, which is now limited, is to reduce the length of the beaches and change sediment dynamics in the surrounding areas.

Reduction in the number of benthic molluscs, the valves of which serve as the initial material for the formation of sands, acts as a background factor and is important for the shallow water areas of Western and partly Eastern Crimea. Extreme technogenic load is observed in Sevastopol and on the Southern coast, and the minimum load is observed on the eastern and northwestern coasts.

REFERENCES

1. Sobel, A.H., Camargo, S.J., Hall, T.M., Lee, C.-Y., Tippett, M.K. and Wing, A.A., 2016. Human Influence on Tropical Cyclone Intensity. *Science*, 353(6296), pp. 242–246. doi:10.1126/science.aaf6574
2. Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Galuszka, A., Cearreta, A., Edgeworth, M., Ellis, E.C. [et al.], 2016. The Anthropocene is Functionally and Stratigraphically Distinct from the Holocene. *Science*, 351(6269), pp. 138–147. doi:10.1126/science.aad2622
3. Dafforn, K.A., Glasby, T.M., Airoldi, L., Rivero, N.K., Mayer-Pinto, M. and Johnston, E.L., 2015. Marine Urbanization: an Ecological Framework for Designing Multifunctional Artificial Structures. *Frontiers in Ecology and the Environment*, 13(2), pp. 82–90. https://doi.org/10.1890/140050
4. Efremova, T.V. and Goryachkin, Yu.N., 2021. Anthropogenic Impact on the lithodynamics of the Coastal Zone of the Southern and Western Black Sea Coast (Review). *Ecological Safety of Coastal and Shelf Zones of Sea*, (2), pp. 5–29. doi:10.22449/2413-5577-2021-2- 5-29 (in Russian).
5. Peshkov, V.M., 2003. [*Coastal Zone of Sea*]. Krasnodar: Lakont, 350 p. (in Russian).
6. Peshkov, V.M., 2005. [*Pebble Beaches of Tideless Seas. Main Problems of Theory and Practice*]. Krasnodar, 444 p. (in Russian).
7. Tsivtsivadze, N., Matchavariani, L., Lagidze, L., Motsonelidze, N., Ivanov, G. and Paichadze, N., 2015. Modern Conceptual and Technological Approaches to the Georgia Black Sea Coastline Protection. *Earth Sciences*, 4(5-1), pp. 46–53. doi:10.11648/j.earth.s.2015040501.19
8. Alpenidze, M., Seperteladze, Z., Davitaia, E., Gaprindashvili, G. and Aleksidze, T., 2015. Natural-Geographical Zoning and Geo-Ecologiacal Problems of Georgia's Black Sea Coast. *American Journal of Environmental Protection*, 4(3-1), pp. 58–66. doi:10.11648/j.ajep.s.2015040301.20
9. Kosyan, R.D. and Krylenko, V.V., 2014. *The Current State of Marine Accumulative Shores of Krasnodar Region and their Use*. Moscow: Nauchnyy Mir, 256 p. (in Russian).

10. Shuisky, Yu.D., 2019. Sea-Port Constructions and their Impact on the Black Sea Coastal Zone. *Odesa National University Herald. Geography and Geology*, 24(1), pp. 53–82. doi:10.18524/2303-9914.2019.1(34).169712 (in Russian).
11. Goryachkin, Yu.N., 2013. Ukraine. In: E. Pranzini and A. Williams, eds., 2013. *Coastal Erosion and Protection in Europe*. London: Earthscan. Chapter 21, pp. 413–426. https://doi.org/10.4324/9780203128558
12. Zenkovich, V.P. and Zhdanov, A.M., 1960. [Why are the Black Sea Beaches Disappearing?]. *Priroda*, (10), pp. 51–54 (in Russian).
13. Korzhenevsky, I.B., Loenko, A.A. and Cherevkov, V.A., 1961. [The Destiny of the Beaches of the South Coast of Crimea]. *Priroda*, (2), p. 60 (in Russian).
14. Korzhenevsky, I.B., 1962. [On Protection of the Beaches of the South Coast of Crimea]. In: Crimean Branch of the Nature Conservation Society, 1962. [*Proceedings of Session of the Crimean Branch of the Nature Conservation Society*]. Simferopol: Krymizdat, pp. 9–12 (in Russian).
15. Zakharzhevsky, Ya.V., 1977. [On Change of the Material Composition and Dynamics of Sand Beaches of Crimea]. *Vestnik Moskovskogo Unviersiteta, Seriya 5. Geografiya*, (1), pp. 102–104 (in Russian).
16. Shuisky, Yu.D., Zambriborshch, F.S., Pedan, G. S., Chernyavsky, A.V. and Berezkina, E.I., 1985. [Influence of Construction Sands Industrial Development ob Coast Dynamics and Zoobenthos State of the Black Sea]. *Vodnye Resursy*, (5), pp. 142–156 (in Russian).
17. Shuisky, Yu.D., Vykhovanets, G.V. and Pedan, G.S., 1987. [Main Findings of the Study of Influence of Underwater Sand Quarries on the Black Sea Coast Dynamics]. In: V. P. Zenkovich, E. I. Ignatov and S. A. Lukyanova, eds., 1987. [*Natural Basis for Coast Protection*]. Moscow: Nauka, pp. 68–82 (in Russian).
18. Agarkova, I.V., 1999. [Economic Activity Influence on the Dynamics of the Saki Coast]. *Scientific Notes of Taurida National V. I. Vernadsky University. Series: Geography*, 12(1), pp. 35–38 (in Russian)
19. Oliferov, A.N., 1997. [Crimean Beaches and their Protection]. *Herald of Physiotherapy and Health Resort Therapy*, (2), pp. 45–49 (in Russian).
20. Oliferov, A.N., 2008. [Dynamics of Crimean Beaches]. *Geopolitics and Ecogeodynamics of Regions*, (1–2), pp. 59–64 (in Russian).
21. Oliferov, A.N., 2011. Status of the Crimean Beaches as Recreation Resource. *Scientific Notes of Taurida National V. I. Vernadsky University. Series: Geography*, 24(2-2), pp. 130–136 (in Russian).
22. Klyukin, A.A., 2004. [Sediment Balance in the Coastal Zone of the Black Sea near the Karadag]. *Scientific Notes of Taurida National V. I. Varnadsky University. Series: Geography*, 17(3), pp. 82–90 (in Russian).
23. Goryachkin, Yu.N. and Dolotov, V.V., 2019. *Sea Coasts of Crimea*. Sevastopol: Colorit, 256 p. (in Russian).
24. Ignatov, E.I. and Sanin, A.Yu., 2013. [Anthropogenic Factor in Functioning of Coastal Morphosystems of the Crimean Coast]. In: MHI, 2013. *Ekologicheskaya Bezopasnost' Pribrezhnykh i Shel'fovykh Zon i Kompleksnoe Ispol'zovanie Resursov Shel'fa* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: ECOSI-Gidrofizika. Issue 27, pp. 353–357 (in Russian).
25. Goryachkin, Yu.N., 2010. Anthropogenic Impact on the Black Sea Coast of Crimea. In: MHI, 2010. *Ekologicheskaya Bezopasnost' Pribrezhnykh i Shel'fovykh Zon i*

Kompleksnoe Ispol'zovanie Resursov Shel'fa [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: ECOSI-Gidrofizika. Iss. 23, pp. 193–198 (in Russian).

26. 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).
27. Goryachkin, Yu.N., 2016. Coast Protections of Crimea: South Coast. *Hydrotechnika*, (2), pp. 34–39 (in Russian).
28. Rybalka, A.T., 1993. South Coast of the Crimea: Environmental Specificity and Coast Protection Problems. In: American Society of Civil Engineers, 1993. *Coastlines of the Black Sea*. New-York: American Society of Civil Engineers, pp. 432–446.
29. Zenkovich, V.P., 1960. [*Morphology and Dynamics of the Soviet Black Sea Coast, Vol. 2*]. Moscow: AS USSR Publ., 216 p. (in Russian).
30. Goryachkin, Yu.N., 2016. Coast Protections of Crimea: West Coast. Part 2. *Hydrotechnika*, (2), pp. 38–43 (in Russian).
31. Goryachkin, Y.N. and Udovik, V.F., 2021. Coastal Protection Structures in Sevastopol Region. *Hydrotechnika*, (2), pp. 30–35 (in Russian).
32. Goryachkin, Yu. N., 2020. Changes in the Yevpatoria Coastal Zone in the Last 100 Years. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 5–21. doi:10.22449/2413-5577-2020-1-5-21 (in Russian).
33. Karabsnikov, M.N., 1927. [Results of Research of Yevpatoria Bay Bottom Rocks]. *Izvestiya Central'nogo Gidrometeorologicheskogo Byuro* [Bulletin of the Central Hydrometeorological Bureau], (7), pp. 184–202 (in Russian).
34. Zenkovich, V.P., 1958. [Coasts of the Black and Azov Seas]. Moscow: Geografgiz. 374 p. (in Russian).
35. Klyukin, A.A., 2007. [Exogeodynamics of Crimea]. Simferopol, 320 p. (in Russian).
36. Goryachkin, Yu.N., Fedorov, A.P., Dolotov, V.V. and Udovik, V.F., 2020. Natural Conditions and Anthropogenic Change of the Coastal Zone in the Area of Kacha Village. *Ecological Safety of Coastal and Shelf Zones of Sea*, (4), pp. 5–21. doi:10.22449/2413-5577-2020-4-5-21 (in Russian).
37. Goryachkin, Yu.N. and Fomin, V.V., 2020. Wave Regime and Lithodynamics in the Region of the Western Crimea Accumulative Coasts. *Physical Oceanography*, 27(4), pp. 415–429. doi:10.22449/1573-160X-2020-4-415-429
38. Dedkov, A.P. and Mozzherin, V.I., 1984. [*Erosion and Sediment Run-off on Earth*]. Kazan: KGU, 264 p. (in Russian).
39. Fokina, N.A., 2007. [Solid Run-Off Reduction as a Result of River Regulation]. In: E. F. Panyukov, ed., 2007. *Construction and Industrial Safety*. Simferopol: Natsionalnaya akademiya prirodookhrannogo i kurortnogo stroitelstva. Iss. 18, pp. 126–131 (in Russian).
40. Shuisky, Yu.D., 2005. Basic Peculiarities of Morphology and Dynamic of the Western Creimea Peninsula Coast. In: MHI, 2013. *Ekologicheskaya Bezopasnost' Pribrezhnykh i Shel'fovykh Zon i Kompleksnoe Ispol'zovanie Resursov Shel'fa* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: ECOSI-Gidrofizika. Iss. 13, pp. 62–72 (in Russian).
41. Pereladov, M.V., 2013. Modern Status and Biological Aspects of Veined Rapa Whelk (Rapana Venosa) in the North-East Black Sea. In: VNIRO, 2014. *Proceedings VNIRO*. Moscow: VNIRO Publishing, Vol. 150, pp. 8–20 (in Russian).
42. Pereladov, M.V., 2005. Modern Status of the Black Sea Oyster Population. In: VNIRO, 2005. *Proceedings VNIRO*. Moscow: VNIRO Publishing, Vol. 144, pp. 254–274 (in Russian).

43. Revkov, N.K., 2003. Taxonomical Composition of the Bottom Fauna at the Black Sea Crimean Coast. In: V. N. Eremeev and A.V. Gaevskaya, eds., 2003. *Modern Condition of Biological Diversity in Near-Shore Zone of Crimea (the Black Sea Sector)*. Sevastopol: EKOSI-Gidrofizika, pp. 200–218 (in Russian).
44. Kopii, V.G. and Lisitskaya, E.V., 2012. Some Aspects of the Biology and Current Status of Population Saccocirrus Papillocercus (Polychaeta: Saccocirridae) in the Coastal Water of Crimea (the Black Sea). *Marine Ekological Journal*, 11(4), pp. 39–44 (in Russian).

Submitted 20.12.2021; accepted after review 14.01.2022;
revised 4.02.2022; published 25.03.2022

About the authors:

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*

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

Contribution of the authors:

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

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

All the authors have read and approved the final manuscript.