ЗАПОВІДНА СПРАВА

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ENVIRONMENTAL THREATS AND RISKS TO PROTECTED AREAS IN THE CONTEXT OF WAR (CASE STUDY OF MOLOCHNYI LYMAN)

Purpose. The study of the ecological state of Molochnyi Lyman, which is a state-level reserve, part of the Pryazovskyi National Nature Park, and a wetland of international importance protected under the Ramsar Convention.

Methods. System analysis, remote sensing data were used, specifically satellite images from Landsat 5, Landsat 8, Sentinel-2, and the software tool Google Earth Engine.

Results. The biodiversity of Molochnyi Lyman is characterized and the impact of the salinity level on its biodiversity is analyzed. Natural and anthropogenic factors affecting the ecological state of Molochnyi Lyman are examined. Special attention is paid to the analysis of the conditions ensuring water exchange with the Sea of Azov and the consequences of its absence for the biodiversity of the water body. The state and dynamics of commercial fish catches in the Sea of Azov (Zaporizhzhia region) and the factors influencing the state of fish resources are analyzed. The impact of the war on the ecological situation in Molochnyi Lyman is assessed, and ways and possibilities to overcome the crisis ecological consequences of the occupation of the territory at the stage of post-war recovery are identified.

Conclusions. The main ecological problems of Molochnyi Lyman are identified: increased salinity, reduced water surface area and biodiversity, as well as siltation of the channels connecting the lagoon with the Sea of Azov. It is proven that the preservation of the lagoon requires stable water exchange and optimal salinity levels, which will ensure favorable conditions for fish spawning and migration, as well as maintain high ecosystem productivity. With the onset of the war, the situation has become more complicated, with additional environmental challenges arising due to inaction, which will require further efforts to restore the biodiversity of Molochnyi Lyman and the Sea of Azov in the future.

KEY WORDS: *Molochnyi Lyman, Sea of Azov, biodiversity, ecological situation, water salinity, water exchange, fish resources*

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Introduction

Molochnyi Lyman is a coastal estuary in southeastern Ukraine, on the coast of the Sea of Azov. Its role and significance are multifaceted; it is a nature reserve of national importance, part of the Pryazovskyi National Natural Park (NNP), and a wetland of international importance protected under the Ramsar Convention. The estuary has significant ecological importance as it is home to many species of fish, birds, and other animals. It is part of the Azov-Black Sea migratory route used by numerous bird species during migration. The estuary is also part of the Pryazovskyi National Natural Park, which contributes to the conservation of natural ecosystems and biodiversity in the region. At the same time, the estuary has economic significance, as it is an important resource for fishing, where commercial fishing of species such as shad, bream, pike-perch, and others is conducted. Additionally, Molochnyi Lyman attracts tourists with its natural beauty and recreational opportunities. Unfortunately, there are a number of ecological problems with Molochnyi Lyman that have been attempted to be resolved over the years. With the onset of the war and the occupation of that part of Zaporizhzhia region where the Pryazovskyi NNP is located, these problems have been compounded by those created by the occupiers as a result of their activities in the protected area, as well as their inaction regarding its protection and development. The aforementioned reasons define the relevance of researching the condition of Molochnyi Lyman in retrospect, including the consequences of the occupation of the territory, which already today have catastrophic significance.

Objects and Research Methods

During the research process, both general scientific methods (analysis and synthesis, induction and deduction, analytical grouping) and specialized methods (abstraction, modeling, etc.) were utilized for studying phenomena and processes. Additionally, remote sensing data were used, specifically satellite images from Landsat 5, Landsat 8, Sentinel-2, and the software tool Google Earth Engine. The object of the study is Molochnyi Lyman.

Results and Discussion

Molochnyi Lyman is located in Northern Pryazovia. Its upper part is fed by the Molochna, Taschenak, and Dzhekelnya rivers, and its lower part is connected to the Sea of Azov, with its shores shaped by aggradation and progradation processes. The area of Molochnyi Lyman is 2200 hectares [1, 2].

Until the 15th century, Molochnyi Lyman was a bay of the Sea of Azov, meaning it was in an open state. It was closed from the end of the 15th century until World War II [3]. After the beginning of World War II, military actions led to the destruction of the embankment, and the estuary became semi-open. The channel width was 400 meters, which facilitated the formation of the Stepanivka mouth. By the 1960s, siltation began, raising the issue of closing this channel and constructing a new one with locks. However, while construction was underway, there were changes in the hydrochemical and hydroecological indicators of the water body [2]. The construction of the new channel did not solve the siltation issue and, due to a poorly chosen site for construction, even accelerated the process of shell deposit accumulation. The semi-open state of Molochnyi Lyman lasted until 1972, and it has been in a semi-closed state to the present day (due to temporary connections and closures) [3]. Throughout this century, problems have arisen due to the reduction in the water surface area and depth, accompanied by an increase in the water body's salinity.

Starting in 2003, the water surface area began to decrease due to low precipitation, river flow, and channel siltation. Under closed estuary conditions, the salinity in some areas can reach even 104 g/dm³. In an open state, the estuary's water salinity reaches up to 25 g/dm³, and under isolated conditions, the salinity fluctuates between 70-90 g/dm³. Between 2005-2014, the area of Molochnyi Lyman decreased by 7.716 thousand hectares. For optimal functioning, it is necessary for up to 100 million cubic meters of water to flow into the estuary annually [2]. However, the most ecologically stable state of the water body is observed in a semi-open state, which is when biodiversity is at its broadest. To support such a stable state, the use of dredging ships and various types of pulp pipelines is optimal. The deposits extracted could be processed into sand or shell [3]. In 2011, the channel to the sea was cleared, and water exchange was restored, but after 1.5 months, the channel silted up again. The salinity of the water increased, creating favorable conditions only for marine species of fish, but unacceptable for freshwater species. In July 2012, a project was developed for an artificial channel to connect the estuary with the sea. The water level began to rise, and salinity decreased [4]. But from the second half of 2014, the channel was cleared again, allowing for water inflow [2].

In 2015, studies showed that the salinity of the water varied: the minimum near the mouth of the channel (15 ‰), over 30 ‰ in most parts of the estuary, and over 50 ‰ in the east. The water surface area of Molochnyi Lyman with stable connection to the Sea of Azov is 20,000 hectares, and 12-15 thousand hectares without connection to the sea. In 2020, Molochnyi Lyman was almost filled with water to optimal levels. Due to the strong current in the channel, shad and atherina entered the estuary for spawning. In the southern part of the estuary, rootmouth jellyfish and aurelia, which are brought by the sea, were encountered. After clearing the shell deposits in 2019, various species of fish returned in 2020, including the important commercial species – shad. In the future, it is necessary for the channel to be stable and to allow the passage of seawater into the estuary to maintain a salinity of at least 17-19 ‰, for effective spawning grounds and migratory processes [4].

However, the recent absence of clearing this connection directly affects the hydrological and hydrochemical state of Molochnyi Lyman and the hydrobionts of this water body. Changes in the hydrochemical composition of the estuary affect the quantity of biota and their species diversity. The hydrology of the water body is influenced by a number of abiotic factors, as well as, as mentioned earlier, the Molochna River and the connectivity with the Sea of Azov. The estuary is isolated from the Sea of Azov by sandy-shell deposits. The length of the estuary is 36 kilometers, and its width varies from 4 to 9 km. The maximum depth of the estuary reaches 3 meters under conditions of stable connection with the Sea of Azov. The minimum depth of 1.5 meters is observed when separated from the sea and at high evaporation levels. Over the past years, Molochnyi Lyman, due to isolation from the sea, has lost approximately 75% of its total volume, significantly affecting the water-salt balance. The most drained areas are located along the left bank, as well as in the upper and lower parts of the estuary, particularly between the villages of Hirsivka and Mordvynivka, along the spit, in the area of Oleksandrivska bay and Lake Molochnyi, due to the position of the bottom. In the 1950s, the channel had a width of over 400 m and a depth of more than 3.5 m. In the 1970s, the width was up to 20 meters, and the depth up to 2.5 meters, while in 2014, after dredging with a clamshell excavator, its width was no more than 20 m, and the depth was 2.5 m. The shallows of the coastal zone prevent seawater from entering the channel, and it only fills during strong storms. Also, in this zone, sand and shell deposits actively move along the shore. Water exchange depends on flood and ebb currents, which are caused by wind, in the case that the water level in the sea and the estuary is the same. Strong eastern and southern winds cause water surges, while northern and western winds cause ebbs. The large amplitude of these fluctuations is due to the fact that the near-mouth part of the water area is far from the nodal line of the sea and is located on its western part. These processes are most pronounced from January to April and November. The height of the surge affects the current speed in the transition zone from the sea to the estuary. Under the conditions of constructing a channel over 400 meters in 1943 and smaller channels in the 1970s, the water level in Molochnyi Lyman reached the water level of the Sea of Azov. To achieve the same water level in the estuary and the sea, it takes 3 months considering all influencing factors for clearing the connection that connects the estuary and the sea. It should also be considered that to reduce the level of salinity, it is necessary to enlarge the connecting channel with the sea to remove excess salts and make the estuary suitable for the migration, spawning, and fattening of hydrobionts [1].

The climate is moderately continental. In winter, the climate is influenced by the Siberian anticyclone, and in summer, by the Azores anticyclone. The weather conditions themselves are affected by the circulation of air masses [4]. From 1969 to 2011, there was an increase in the sum of positive temperatures, over 15 degrees Celsius, which directly affects the evaporation of water in Molochnyi Lyman. In addition to temperature, the hydrology of the estuary is also influenced by the flow of the Molochna River. However, the flow and tributaries are regulated. The hydrology of Molochnyi Lyman is also affected by an anthropogenic component, such as an artificially created connection, which is silted with shell-sand deposits [2].

In the open state, when it is connected to the sea, bioproductivity is high, water salinity ranges from 17-25 g/l, and the diversity and number of hydrobionts are significant. In the closed state, when the estuary is separated from the sea, salinity increases to 30-90 g/l, which negatively affects the hydrobionts and reduces the productivity of the water body. In this case, biodiversity decreases, water salinity changes, fish productivity decreases, the risk of fish kills increases, and the diversity of the ornithofauna decreases [5,6].

The ecological connection between the sea and the estuary allows the mixing of waters with different salinities. Common consequences of disrupting this connection include the loss of natural habitats, increased turbidity, the influx of nutrients, changes in the dynamics of the estuary and its connections, and loss of biodiversity. Through conservation measures to maintain the connection between the estuary and the sea and to support ecological balance, it is possible to save wetlands from degradation and to maintain a stable and optimal level of salinity [7]. Additionally, estuaries may be threatened by the influx of biogenic substances, which can occur due to excessive anthropogenic impact (wastewater rich in organics) [8]. In light of this, it is necessary to review the situation with regulated rivers that supply Molochnyi Lyman with fresh waters.

It is also necessary to consider the concepts of ecohydrology, which propose integrated management of estuarine ecosystems through an understanding of the interconnections between physicochemical features, ecological niches, and community desires. This approach includes analyzing natural processes and anthropogenic impacts with the goal of sustainable management of water resources and ecosystem conservation. The core principles include regulating hydrological processes, supporting ecological functioning through interactions in ecosystems, considering feedback loops between biological and physicochemical systems, as well as the impact of human activities on these processes. The proposed solutions involve the use of comprehensive management measures, including control of water resources and hydraulic infrastructure, to restore the ecosystem and ensure sustainable development [9-12].

Characteristics of the biodiversity of Molochnyi Lyman.

Ichthyofauna. Molochnyi Lyman plays a crucial role in the spawning and fattening of ichthyofauna. This water body supports the natural reproduction of commercially important fish species such as *Liza haematocheilus* and *Platichthys luscus*. It is also conducive to the spawning of other fish species such as *Neogobius melanostomus*, *Neogobius fluviatilis*, and *Zosterisessor ophiocephalus*. In terms of the impact of hydrochemical indicators on ichthyofauna, there are species changes in biodiversity, while quantitative indicators remain stable. Due to hydroecological changes in Molochnyi Lyman, there is a decrease in the population of *Percarina demidoffii*, *Esox luceus*, *Acipenseridae*, *Neogobius eurycephalus*, *Trachurus ponticus*, *Scardinius erythrophthalmus*, *Alosa maeotica*, *Mullus ponticus*, *Pegusa lascaris*, *Neogobius ratan*, *Syngnathus nigrolineatus*, *Neogobius syrman*, and *Carassius gibelio*. The reduction in water level, increase in land area, and increased salinity of the water body reduce the species diversity of ichthyofauna [5,6]. Molochnyi Lyman is an important zone for spawning (of shad and flounder) and a site for the fattening (of gobies, sea roach, shad, Black Sea mullets, syngnaths). The year 2002 was one of the most critical in terms of salinity and water levels, impacting the aquatic inhabitants. There was also a negative impact on the surrounding avifauna due to the merging of islands with the mainland. Species like the needlefish, spiny dogfish, and marbled goby were under the threat of extinction, while the rest of the species were in a critically depressed state [13]. In 2018, siltation occurred again, preventing water from the Sea of Azov from entering the estuary, which increased the salinity of the water to over 60 ‰. In 2019, the channel was restored, allowing water from the Sea of Azov to flow into Molochnyi Lyman again.In 2021, gobies, shads, and mullets began to spawn. In 2021, the salinity of the estuary reached 42.5‰ in the north and 47.7‰ in the middle, making it an ultra-saline water body, as the salinity exceeded 40‰. The pH values fluctuated between 8.2 and 8.6. However, the aeration conditions were well suited for those ichthyofauna species that prefer medium to high oxygen levels, as it contained 5.8-7.9 mg/l of oxygen at temperatures of 21.8-22 degrees Celsius [4].

In Molochnyi Lyman, according to researchers, there are 8 fish species listed in the Bern Convention, 2 species in the IUCN Red List, and 1 species in the Red Book of Ukraine. In the southern part of the estuary, the presence of Azov shemaya was noted; however, excessive silting already in 2002 disrupted its migratory paths. Ichthyofauna listed in conservation lists and observed in Molochnyi Lyman include: Azov shemaya (Red Book of Ukraine); Common carp and Snakehead goby (IUCN); Azov shemaya, Common sabrefish, Southern spiny stickleback, Potbellied seahorse, Syrman goby, Sand goby, Snakehead goby, and Blunt-snouted clingfish (Bern Convention). Among all the water bodies in the northwestern zone of the Sea of Azov, Molochnyi Lyman has the least diversity of fish species. Studies have shown the detrimental effect of increased water salinity on rare fish species. Specifically, the level of salinity, i.e., mineral substances, affects the ichthyofauna under protective status as a limiting factor. This, in turn, requires immediate response to the current situation around Molochnyi Lyman to prevent the loss of natural spawning, migration, and fattening areas for diadromous and semi-diadromous fish. Moreover, this is caused not only by silting of the channel but also by the regulation of the Molochna River [14].

Coastal fish species that predominated in observations in 2021 included Proterorhinus semilunaris, Atherina boyeri pontica, Mugil soiuy, Neogobius fluviatilis, and Zosterisessor ophiocephalus. Also encountered was the ctenophore Mnemiopsis. Regarding an interesting commercial object from the goby family, in 2020, species such as Proterorhinus semilunaris, Zosterisessor ophiocephalus, and Neogobius fluviatilis were observed. Since Zosterisessor ophiocephalus spends all its life stages in the estuary, this species is the most common for commercial fishing at present, and its biomass is the largest. The connection of the sea with the estuary will ensure the development of populations of each of the mentioned species from the goby family. The preservation of Molochnyi Lyman is also important because it is a crucial water body for such an acclimatized commercial species as shad [4]. The best salinity levels for fish diversity are close to 25 g/dm³. Under such conditions, optimal development of ichthyofauna is possible. The estuary's ecosystem suffers from an unsuccessful anthropogenic hydrological regime, which necessitates the restoration of the connection between the estuary and the sea to maintain this unique area with rare species of biota [13].

Zooplankton and zoobenthos. Zooplankton is represented by the genera Acartia, Artemia, Canuella, and Brachionus. Also present in Molochnyi Lyman were Oscillatoria, Prorocentrum, Peridinium, Coscinodiscus, Thalassiosira, Nitzschia. Molochnyi Lyman is a very important site for the spawning of commercial fish species, particularly shad. As for the animals represented in the plankton, the majority are members of ultra-saline ecological groups. The most common are Acartia tonsa and Acartia clausi. Canuella perplexa and Brachionus quadridentatus were also found in large numbers. Dominant species that thrive in ultra-saline waters include Artemia salina and Artemia calina, which have a wide range of salinity tolerance – euryhaline. In the pelagic zone, gastropods, foraminifera, and polychaetes were encountered. The zoobenthos is largely represented by Chironomus salinarius, Gammaridae, and Cerastoderma. The biomass of the zoobenthos was low [4].

Invertebrate animals of Molochnyi Lyman are of particular interest for study due to the constant changes in the connection with the Sea of Azov, as the ecological state of the water body frequently changes [15]. There are about 88 species of benthic invertebrates. Approximately 50 species of mollusks and 30 species of crustaceans have been studied. The center of the estuary is the saltiest, while the northern and southern parts are less saline. Salinity correlates with biomass, which is higher in the southern and northern parts of the estuary, with the largest share accounted for by mollusks. When the estuary is separated from the sea, there is an increase in water salinity, a decrease in species diversity, and a drop in biomass [13]. In 2019, 75 taxa of zoobenthos were recorded in the Sea of Azov, Molochnyi, and Utlyuk estuaries. However, in Molochnyi Lyman, only 2 species were present because the amount of water was extremely low and there was an increase in salinity levels. Therefore, residents of very saline waters, Chironomus plumosus and Artemia salina, were found there. The salinity of the water that year reached 60-120‰. Molochnyi Lyman was characterized by high indicators of abundance and biomass, but due to the increased salinity of the water, these indicators suffered significant reductions [16, 17].

Ornithofauna. Molochnyi Lyman is a unique area for stopovers, wintering, and settlement of birds, which is why it is classified as a wetland and is protected. 15 bird species are listed by the IUCN, 259 species are protected under the Bern Convention, 147 species under the Bonn Convention, 96 species are protected by the Agreement on the Conservation of African-Eurasian Migratory Waterbirds, 41 species are under CITES protection, and 44 species are protected by the Red Book of Ukraine. This protected area is home to about 20,000 individuals of wetland birds [5,6]. Over the last century, 269 diverse species have been identified at Molochnyi Lyman, 57 of which are listed in the Red Book of Ukraine. Birds are attracted to this area by the food base and favorable nesting conditions. Hydrological changes affecting Molochnyi Lyman significantly impact bird nesting. In particular, a large number of terns, gulls, and cormorants have lost nesting sites as the Long and Horseshoe islands have disappeared. The decrease in freshwater inflow increases salinity, which hinders the normal existence of these species. Increased areas of dry land and disappearing stretches in the northern part of the estuary (which belongs to the wetlands) affect the reduction of areas where gray geese, herons, ducks, foxes, terns, and passerines can nest. The disappearance of salt marshes on the coast leads to the loss of natural habitats for red-listed species (Recurvirostra avosetta, Haematopus ostralegus, Himantopus himantopus, Charadrius alexandrinus, Glareola pratincola). For these reasons, the number of birds in the area protected by the Ramsar Convention has decreased. The number of bird species in the Wetlands of International Importance has halved from 1998 to 2012. Meanwhile, the reproduction rates of birds in this protected area have decreased to levels ranging from 0 to 30%. The cause of this phenomenon is precisely the reduction in water levels. The quantity and species diversity have decreased due to high salinity and the lack of a food base. During the nesting period, Molochnyi Lyman does not meet the criteria of the Ramsar List. In the post-nesting period, the number of birds meets the criteria of the Ramsar Convention, but there is a change in their taxonomic groups. Molochnyi Lyman is losing its Ramsar criteria [5, 6]. Additionally, there are ornithological sites within the Pryazovskyi National Nature Park, mostly near or within Molochnyi Lyman (Mordvynivka Depression, Stepanivka Spit, the delta of the Molochna River). There are also entomological sites close to Molochnyi Lyman on the right bank of the estuary and on Stepanivka Spit [18].

Flora. The flora of the studied region consists of Holarctic and European-Mediterranean species. The hydrophyton includes elements of coastal-aquatic and aquatic cenoses. The study area contains a large number of representatives from the families Magnoliopsida and Liliopsida, which include subendemic species unique to this area. The islands of the studied territory feature confinative subendemics, more characteristic of the Pryazovia region. This also highlights the uniqueness of this region and the necessity for further conservation and maintenance efforts. The sea receded from Pryazovia in the Miocene epoch, and since then, it has been a place for flora development. The region of southern Ukraine, between the Dnieper riverbed and Molochnyi Lyman, was a site for the development of terrestrial flora during the Quaternary period. This fact confirms the presence of localized South Black Sea steppe endemism. In the Holocene, species from the Pontic center spread to the studied territory, including Galatella villosa. The flora of the area belongs to the feather grass-tussock grass zone. On the islands of Molochnyi Lyman, there are fragments of Ammophiletea and Cakiletea maritimae associations, which constitute so-called littoral vegetation. In the area of Molochnyi Lyman, unique species such as Asparagus pallasii and Tamarix gracilis, which are unique to Ukraine and the world, have been found. Species such as Astragalus borysthenicus and Asparagus pallasii are found only on the islands of the studied area. Species of the genera Stipa and Tamarix are dominants and subdominants of the studied region and are also considered rare phytocoenoses. The studied region requires special protection due to the presence of littoral endemics, halophytes, and coastal-aquatic vegetation (Astrodaucus littoralis, Centaurea odessana) [19]. In the second half of the 20th century, studies of the algal flora in Molochnyi Lyman identified 63 species in the phytoplankton and 100 species in the phytobenthos [20, 21]. The phytoplankton is represented by Dinoflagellates, Diatomaceous algae, Cyanobacteria, and Green algae. The coast is characterized by the presence of Cladophora, while in the deeper part of the estuary, Thalassiosira, Nitzschia, Prorocentrum, Peridinium, Coscinodiscus, and Oscillatoria are encountered. The largest portion of the algae consisted of species such as Cyclotella sp., Nitzschia tenuirostris, Campylodiscus sp., Nitzschia punctata [4].

As noted above, the presence of a connection between Molochnyi Lyman and the Sea of Azov, and consequently the level of water salinity in the estuary, is the most influential factor affecting biodiversity in the estuary. Therefore, let's analyze the impact of salinity on the state of fish resources in the estuary in more detail.

Literature analysis shows that over its history, four main stages (states of connection) of Molochnyi Lyman with the Sea of Azov can be distinguished:

1) Open estuary (until the 15th century), when it was a bay of the Sea of Azov and the salinity level of the water corresponded to the level of seawater [22];

2) Closed estuary (from the end of the 15th century to 1943), when it was a salt lake and the water salinity level ranged from 25‰ in 1929 to 60‰ and more in 1939;

3) Semi-open estuary (from 1943 to 1972), when there was a possibility of water exchange with the Sea of Azov through a wide channel (for some time – two), hence the water salinity level was 14.0 - 22.6‰) [22];

4) Semi-closed estuary (from 1972 to 2019), when water exchange with the Sea of Azov occurred through one artificial channel, which periodically silted up with sand, the water salinity level fluctuated from 34.2 to 96‰.

Throughout this time, rivers flowed into Molochnyi Lyman, primarily the Molochna River, but its flow level gradually decreased.

According to research results [23], at the beginning of the 20th century, the sandy-shell spit between Molochnyi Lyman and the Sea of Azov was eroded, and more freshwater from the sea entered the estuary. This occurred in 1909, 1929, 1931-1932, and 1940. However, each time the channel existed for no more than a year, it was again filled with sandy-shell deposits, and Molochnyi Lyman became closed again.

In 1943, during World War II, German troops deliberately blew up the spit, creating a channel that was deep enough, and further eroded during autumn storms and spring – it did not silt up. From that moment, for a certain period, the estuary again became a semi-open water body.

In the mid-20th century, according to N.O. Alexeyev, the main methods of water exchange for Molochnyi Lyman were: the inflow of sea water through one (two) channels, evaporation from the water surface (depending on temperature), stormwater runoff into the water area from its shores, wind-driven and seiche flows, and the inflow of fresh water (rivers Molochna (formerly Sutin), Taschenak, Dzhekelnya and their tributaries) [22].

During this period, sea water entered through the main channel, up to 400 meters wide, and also through a second flow – the so-called "Stepanivske mouth," which ensured the influx and circulation of sufficient water to maintain a lower salinity level. This continued until 1965 when the processes of shallowing of the first mouth and silting of the second intensified. Unfortunately, over time, it turned out that the decision to create a new channel instead of deepening the existing one was mistaken. Initially, in 1972, Molochnyi Lyman again became closed during the construction period. However, the new channel did not solve the problem, as the chosen location proved to be unsuitable; it quickly filled with sandy-shell deposits and required periodic dredging, which continued until 2003. In the following years, dredging and clearing were conducted sporadically, thus accelerating the processes of shallowing of Molochnyi Lyman, reducing its area, and increasing the water salinity level.

The main sources of freshwater supply were and remain rivers, the characteristics of which are presented in Table 1.

Table 1

Characteristics of the rivers flowing into Molochnyi Lyman

Name of the river	Length of the river, km	Watershed area, km²	Number of tributaries	Total length of tributaries, km
Molochna	197,0	3450,0	80	178,0
Taschenak	62,2	467,8	3	36,0
Dzhekelnya	34,8	228,0	-	-

But, today, these steppe rivers have almost lost their significance as a source of fresh water replenishment for the estuary due to shallowing and regulated surface runoff: numerous ponds and reservoirs have been created along their channels and floodplains. According to [2], over the years, the level of surface runoff has fluctuated between 13.87 - 154.96 million m³, averaging 53.46±5.45 million m³.

The period from 1972 to 2019 was the most challenging for the biodiversity of the estuary, as due to the instability of water exchange, fluctuations in water levels, there were periodic dryings of shallow areas, and the water receded hundreds of meters from the shore, consequently – as a result - the level of salinity also fluctuated. During this period, differences in the hydrochemical and hydrological state of the upper, middle, and lower parts of the estuary, which had existed up to that time, virtually disappeared, making the water body's ecosystem unstable in terms of dynamics and species composition.

From 2001 to 2013, Molochnyi Lyman periodically became closed (in 2001, 2002, 2006, 2007, 2008). For example, in 2001, the shad that entered Molochnyi Lyman for spawning due to the silting of the channel could not return to the sea and died in tons in the estuary. Instead of deepening the channel, a new channel project was developed in the Pryazovia area.

As a result, from 2003 to 2013, the water area of Molochnyi Lyman decreased from 21,269 hectares in 2003 to 14,229 hectares in 2013. Accordingly, the salinity of the estuary increased from 30.0‰ in 2003 to 82.5‰ – 104‰ in 2013.

These negative changes led to a significant reduction in the species richness of fish several times. Thus, according to field research by Demchenko V., in 2012 only 4 fish species were registered – mullet, shad (Liza haematocheilus), Black Sea flounder (Platichthys flesus), grass snakehead goby (Zosterisessor ophiocephalus), and Black Sea silverside (Atherina pontica).

Another critical situation occurred in the summer of 2017, when about 17,000 individuals of shad, weighing from 0.5 to 3 kg each, died in Molochnyi Lyman.

Therefore, from the beginning of 2018 to December 2019, comprehensive work was carried out to clear the connecting channel and restore the semi-open state of Molochnyi Lyman, which led to a decrease in the water salinity level and created conditions for the recovery of population numbers of the main commercial fish of the Azov Sea.

Unfortunately, periodic silting of the channel between Molochnyi Lyman and the Sea of Azov poses a significant threat to the biodiversity of both the estuary and the sea.

The state of fish resources in the Sea of Azov significantly depends on providing conditions for the spawning and fattening of fish in Molochnyi Lyman. We have conducted studies on the situation regarding the commercial fishing of fish resources in the Sea of Azov.

First and foremost, this concerned fish such as shad. An analysis of shad catch in the Sea of Azov was conducted for the years 2010 – 2021. In 2022 – 2023, with the onset of the war, fishing activities in the Sea of Azov ceased due to the occupation of the territory (Fig. 1).

As we can see, from 2010 to 2013, both the catch volumes and the corresponding limits were decreasing, and in 2014 – 2015, the catch level reached catastrophically low values. A gradual improvement in the situation occurred during 2020 – 2021. Let us explain the reasons for these changes.

The decrease in shad catch by 2014 occurred due to the gradual silting of the channel between the sea and the estuary and the complication of fish spawning. In 2014 - 2015, the channel was partially cleared, and Molochnyi Lyman was reconnected with the Sea of Azov.

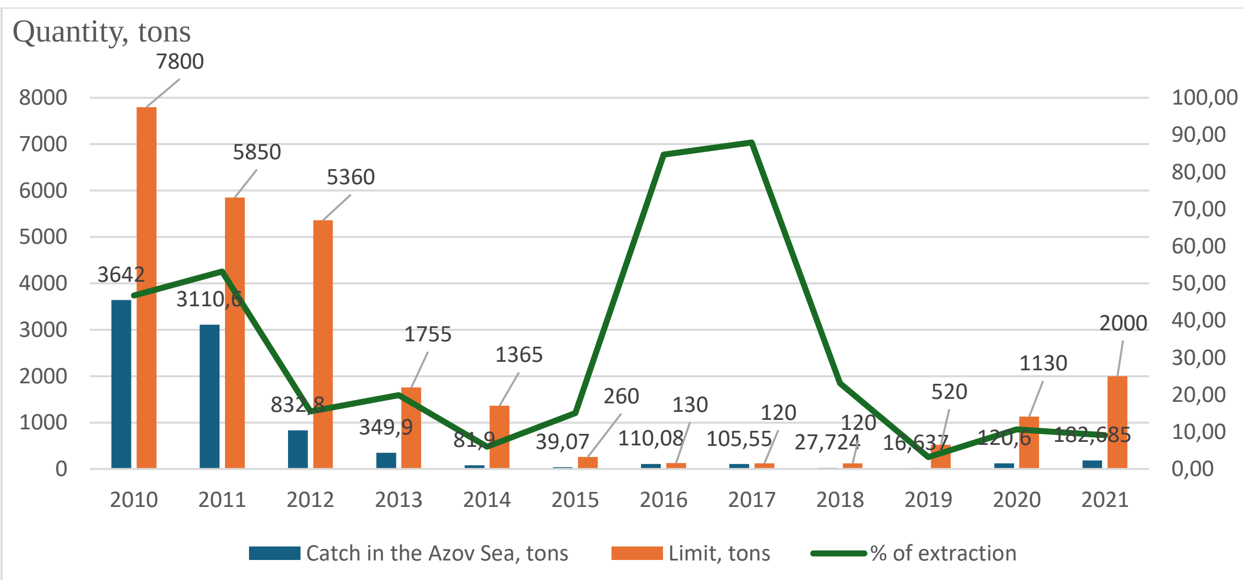

Fig. 1 – Shad catch in the Sea of Azov from 2010 to 2021
Constructed based on data from analytical source [24].

This led to certain positive results, including a rise in water levels and an increase in the estuary's water area. Accordingly, this allowed a slight increase in catch volumes from 39.07 tons in 2015 to 110.08 and 105.55 tons in the following years, respectively. In 2018, the situation deteriorated again, resulting in the catch volume in the Sea of Azov dropping to catastrophically low levels – 16.637 tons. For comparison, in 2010, the shad catch amounted to 3642 tons per year.

The analysis of fish catch data in the Sea of Azov after the channel deepening in 2018 – 2019 significantly increased the shad catch to 182.658 tons per year in 2021. Unfortunately, this figure is much lower than the 2010 indicators but significantly better than the situation in 2018. Therefore, there was every reason to expect further improvement in the coming years. However, the start of the war in 2022 made its adjustments, as the mentioned area came under occupation.

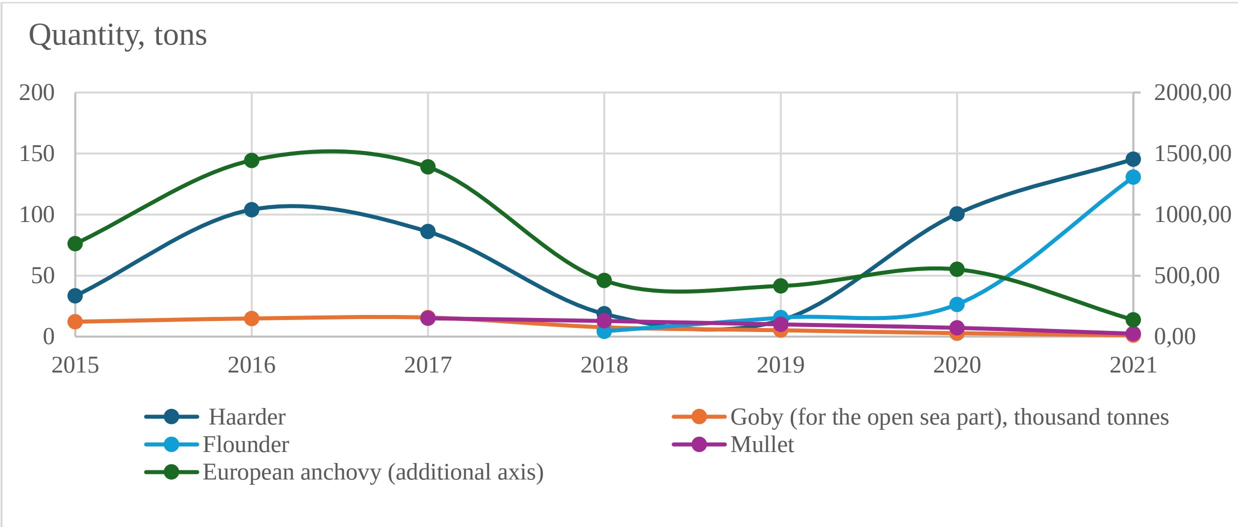

Fig. 2 – Catch volumes of the main commercial fish in the Sea of Azov in the Zaporizhzhia region
Constructed based on data from the State Statistics Service of Ukraine [25].

We also conducted an analysis of the catch volumes of the main commercial fish in the Zaporizhzhia region during 2015 – 2021 (Fig. 2).

As we can see, from 2015 to 2021, there are negative trends - fish catch volumes are decreasing. The exceptions were the catch volumes of flounder (turbot) and shad after the channel deepening in 2018-2019, which significantly increased in the subsequent years of 2020 – 2021. Therefore, there were all possibilities to expect an improvement in the situation further since a decision was made regarding the periodic (systematic) dredging of the channel between Molochnyi Lyman and the Sea of Azov.

Currently, there are several threats existing for Molochnyi Lyman. Firstly, there is the increase in the salinity of the Sea of Azov. If there is a constant (sufficient) connection between the sea and the estuary, it is possible to reduce the salinity of the water in Molochnyi Lyman. If the salinity level in the sea increases – the degree of salinity reduction in the estuary becomes significantly lower. From 1997 to 2003, the salinity level of the Sea of Azov fluctuated slightly and was 10.27‰, from 2003 to 2006 – it somewhat decreased to an average of 9.72‰. From 2007 to 2012, there was a quite sharp increase in salinity to 13‰ (average value – 10.64‰). In 2020, the salinity was already 14.5‰ (in some areas of the sea it exceeded 15‰). Thus, as we can see, the salinity of the Sea of Azov is approaching the level of the Black Sea, where it is 17-18‰. It should also be considered that in some areas of the sea it is higher than the average value. Thus, in the western part of the Sea of Azov – it is 14‰, and in the Utlyuk estuary - 16-17‰. The main reason for the increase in the salinity of the Sea of Azov is the decrease in the inflow of fresh water with a simultaneous increase in the inflow of more saline water from the Black Sea. Currently, through the Kerch Strait, there has already formed a fairly constant current of saltier water from the Black to the Azov Sea. There is also a continuous decrease in the flow of the Don and Kuban rivers, which respectively brought 70 and 30% of fresh water to the sea. Today, this amount is even less. This happened due to the regulation of runoff (Tsimlyansk Reservoir) and an increase in water intake primarily from the Don River. In the Sea of Azov, the amount of fresh water has decreased on average by 9 km³ annually. The daily productivity of runoff in the summer is critical because agricultural producers use water for irrigation of fields. Water consumption in the Rostov region is also increasing annually (on average 0.5 million m³ of water per day).

Since the start of the war, the situation has become even more complicated, as from 2023 Russia has been diverting an additional 300,000 cubic meters of water per day from the Don River for the needs of the DPR and Mariupol. Before the war, water supply was carried out through the

North Donetsk – Donbas canal, which became shallow as a result of the destruction of the dam of the Oskil Reservoir in the Kharkiv region.

According to experts [26], the partial filling of the Kalchyk River with slag has reduced the inflow of fresh water into the Sea of Azov by almost three times.

Such changes in the salinity level of the Sea of Azov differently affect the living conditions of various fish. For example, the increase in the salinity of the Sea of Azov has improved the spawning conditions for the Azov turbot and shad. However, a necessary condition for the spawning of these fish species is not only the salinity level of the sea but primarily the existence of a connection and water exchange between Molochnyi Lyman and the Sea of Azov. Shad enters Molochnyi Lyman for spawning, so the water salinity level there must be suitable for this. Especially since the amount of fresh water that reaches there through the Molochna River in recent years is insignificant in terms of its impact on reducing water salinity.

The opposite situation is with the Azov goby, for which a significant natural problem is the increase in water salinity in the Sea of Azov to 15‰, since the critical salinity value, above which conditions for the spawning of the main commercial species of goby – round goby, become unfavorable – is 13‰. The analysis conducted above showed that a critical situation with spawning had already occurred in 2020, which is why the State Fisheries Agency was forced to completely abandon all types of spring fishing for gobies in the Azov basin [27, 28].

Our analysis showed that over the last 10 years there has been a gradual decrease in the catch volume of Azov goby, which is a result of its decreasing population in the Sea of Azov. There is reason to believe that the increasing salinity of the water in the sea also has a negative impact on this.

In addition to the increase in the salinity of the Sea of Azov, additional environmental threats to Molochnyi Lyman have arisen since the start of the war due to the entry of contaminated water into it through the Molochna River and from the Sea of Azov.

Today, in temporarily occupied Mariupol near the Kalchyk River, the invaders have created a landfill. As a result – there have been numerous cases of dead dolphins and fish washing up on the shores of the Sea of Azov. In turn, contaminated seawater further enters the estuary.

The Molochna River in occupied Melitopol, Zaporizhzhia region, is also on the verge of an ecological disaster. The river periodically becomes silted, turns white, is covered with white foam, and acquires a sharp unpleasant odor. Experts believe that the most likely cause of this pollution is sewage leaks, which are not promptly prevented and remedied, resulting in sewage entering the river.

Before the war, problems with the entry of municipal wastewater existed, but previously municipal services regularly maintained the river, and law enforcement held those responsible for pollution accountable. In 2021, the river began to be cleared, but these works were not completed before the occupation.

The situation with wastewater in another occupied city of Zaporizhzhia region – Tokmak, is complicated. Due to periodic problems with electricity and fuel supply, sewage enters the Molochna River. Even under normal operation of treatment facilities, discharges of inadequately treated return water occur in the cities of Tokmak and Melitopol, significantly worsening the ecological state of the Molochna River and consequently - the estuary.

Furthermore, today the Molochna River continues to shallow and become overgrown with reeds, but the occupying authorities are not taking any measures to save it.

There is every reason to expect negative impacts from the military training ground that the occupiers set up near Molochnyi Lyman in the territory of the Radivonivka forest. Therefore, this issue, in our opinion, requires additional attention.

Thus, all this together accelerates the onset of an ecological disaster for Molochnyi Lyman.

With the onset of the war and the occupation of parts of the Zaporizhzhia region (Pryazovskyi National Park – completely), due to the inability to conduct field research in the Molochnyi Lyman area, we used remote sensing (RS) tools to assess the consequences of the occupation for the estuary. First and foremost, the status of the connection between Molochnyi Lyman and the Sea of Azov, as its absence had already led to catastrophic ecological consequences.

An analysis of satellite images of the channel connecting Molochnyi Lyman with the Sea of Azov was conducted. Using the software product Google Earth Engine, images of the territory for 2013, 2015, 2017, 2019, 2021, and 2023, as well as from January to May 2024, were obtained. Images up to 2015 were created based on data from the Landsat 8 satellite, while from 2015, images with higher resolution from Sentinel-2 were used.

In Fig. 3, the location of the channel where the dynamics of changes caused by natural silting with shell deposits and clearing with special equipment were studied is marked with a green dot.

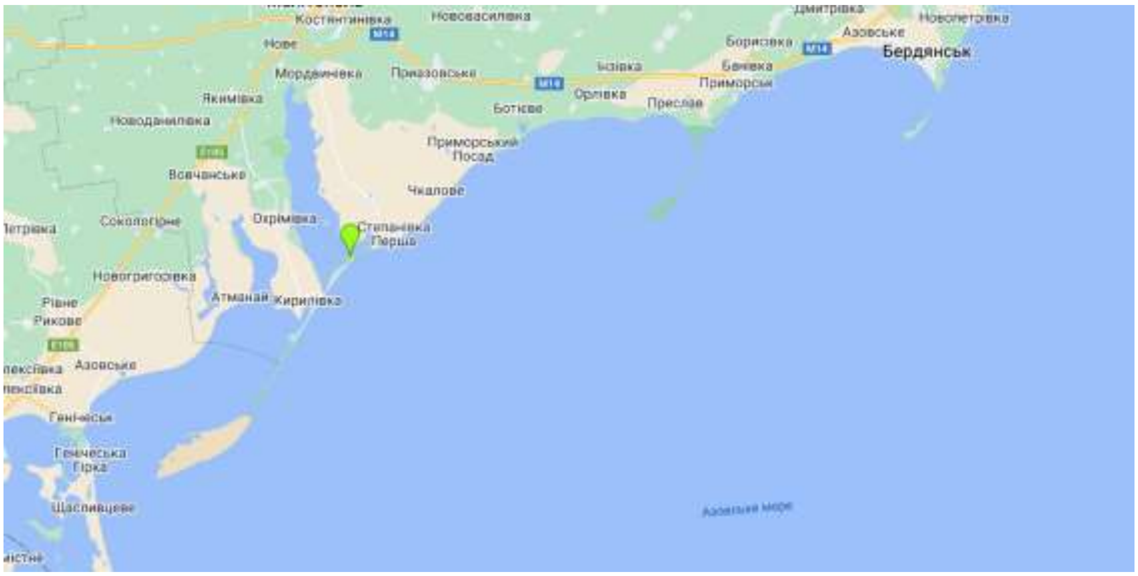

Fig. 3 - Research site: the channel connecting Molochnyi Lyman with the Sea of Azov
The data obtained using the Google Earth Engine software

After determining the observation point, an averaged image for the year 2013 was obtained (Fig. 4). According to it, the level of silting with sandy-shell deposits was extremely high, which hindered the inflow of sea water into Molochnyi Lyman. The situation in 2013 was critical, and the state of this connection significantly affected the aquatic organisms.

However, by 2014, clearing works had been conducted, resulting in an increased width of the channel by 2015, as confirmed by images from that year. The situation improved, spawning and fattening began to occur more effectively, and the productivity of biomass accordingly increased (Fig. 5).

In 2017, the situation deteriorated again, with silting of the estuary-sea connection occurring (Fig. 6). The process of silting with shell deposits occurred rapidly, again affecting the biodiversity of the protected natural area.

Satellite images from 2019 to 2021 show that the channel became much wider as it was cleared of silt in 2018 - 2019 (Fig. 7 and 8). As a result, in 2020, many species of fish returned to Molochnyi Lyman, with an increase in population numbers and species diversity. Additionally, commercial fish species also returned due to the favorable hydrological and hydrochemical conditions of Molochnyi Lyman.

However, the images from 2023 and the first half of 2024 (Fig. 8 and 9) show silting of the channel, which is a negative factor for the biodiversity of the estuary. The situation requires immediate resolution, as it will affect the spawning, fattening, and migration of the ichthyofauna, as well as the ornithofauna of the wetlands in the near future. The silting situation is cyclical, and for the optimal functioning of Molochnyi Lyman and the maintenance of an ecologically balanced state, it is necessary to constantly clear the channel or create special structures. This will prevent re-silting, ensure free water exchange between the estuary and the sea, maintain high biomass productivity, and preserve biodiversity.

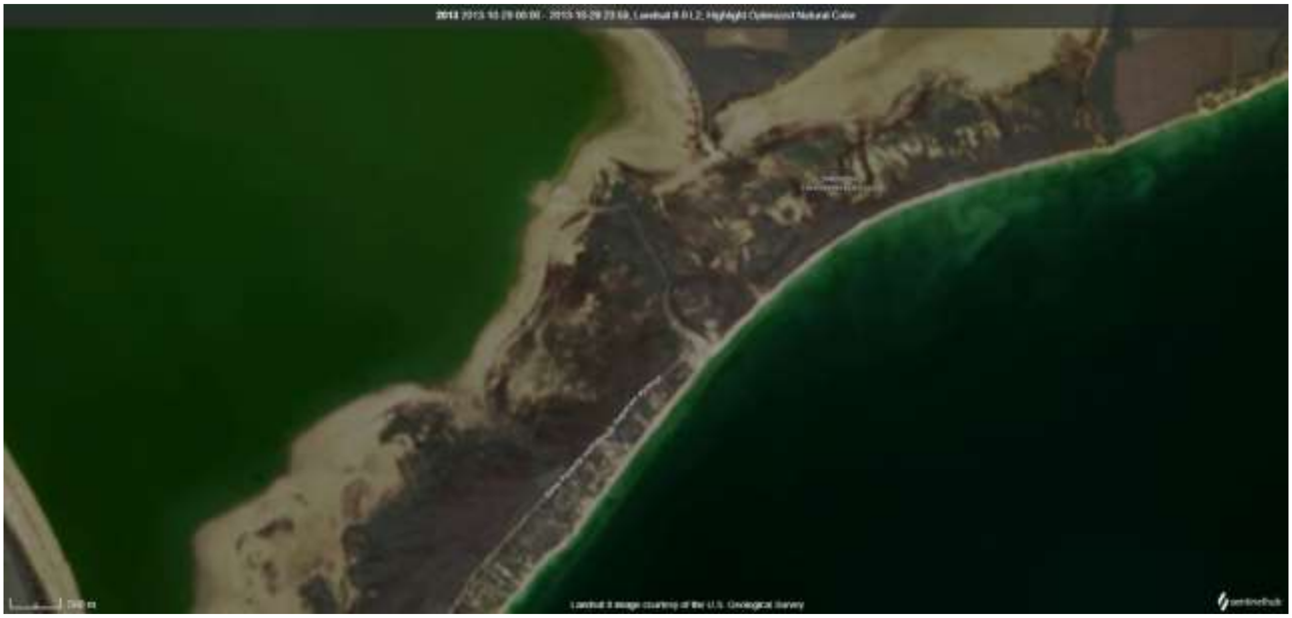

Fig. 4 - Landsat 8 satellite image of the studied area from 2013
Images of the area obtained using the Google Earth Engine software

Fig. 5 - Landsat 8 satellite image of the studied area from 2015
Images of the area obtained using the Google Earth Engine software

Fig. 6 - Sentinel-2 satellite image of the studied area from 2017
Images of the area obtained using the Google Earth Engine software

Fig. 7 - Sentinel-2 satellite image of the studied area from 2019
Images of the area obtained using the Google Earth Engine software

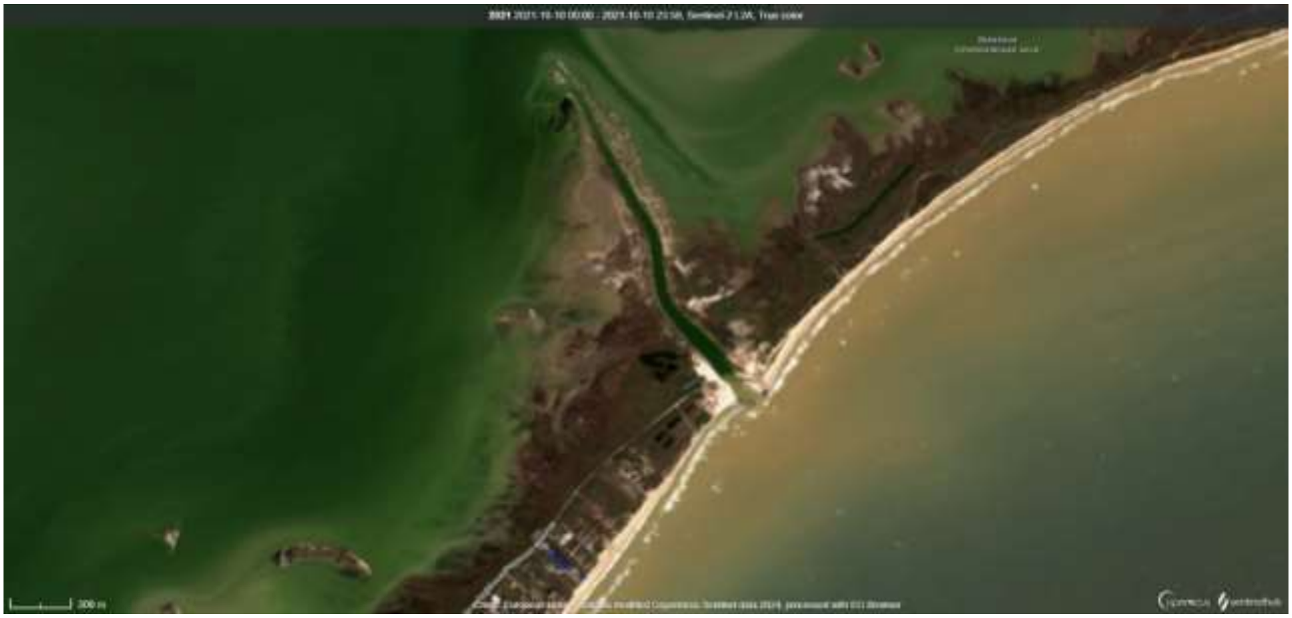

Fig. 8 - Sentinel-2 satellite image of the studied area from 2021
Images of the area obtained using the Google Earth Engine software

Fig. 9 - Sentinel-2 satellite image of the studied area from 2023
Images of the area obtained using the Google Earth Engine software

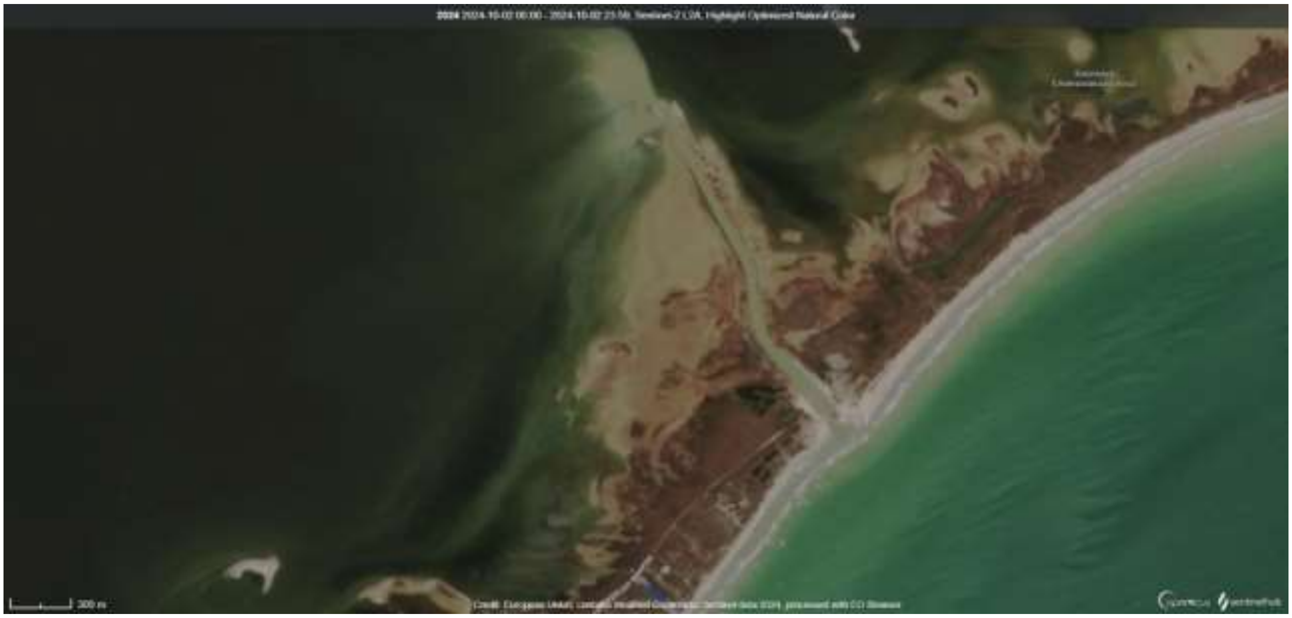

Fig. 10 - Sentinel-2 satellite image of the studied area from 2024
Images of the area obtained using the Google Earth Engine software

Additionally, a study of the water surface area was conducted for the years 2013, 2015, 2017, 2019, 2021, and 2023 using the Google Earth Engine software, utilizing satellite images from Landsat 5, Landsat 8, Sentinel-2. In 2013, the water surface area of Molochnyi Lyman significantly decreased at the head and on the right side (Fig. 10). This reduction was caused by the absence of water inflow from the Sea of Azov, which led to a significant increase in water salinity. The strictly protected zone at the head of the estuary, where the water receded, was severely affected. This place is important for nesting a large number of birds due to the wetlands. Thus, the ornithofauna also suffered negative impacts due to the changing conditions in Molochnyi Lyman. In 2015, the water surface area significantly increased, and the areas where water had receded in 2013 were refilled (Fig. 11).

This created favorable conditions for the settlement of wetland birds along the coast. According to the images from 2017 and 2019, water began to recede again at the head and the lower reaches of the estuary due to the silting of the channel (Fig. 12 and 13).

The wetlands at the head of the estuary, which are protected by the Ramsar Convention, suffered adverse effects, negatively affecting bird populations. There is also a trend that when there is no water inflow to the estuary, dry land appears at the head, lower reaches, and also on the right side of the estuary.

However, after the channel clearing work conducted, in 2020 the water refilled almost the entire territory of the estuary (Fig. 14). According to the 2021 images, the water surface area significantly increased, creating favorable conditions for the effective functioning of both adjacent terrestrial ecosystems and aquatic ones in particular. However, according to the 2023 images of Molochnyi Lyman, the silting situation is repetitive. Because of this, the water surface area is consistently decreasing (Fig. 15).

Although clearing works were conducted on the channel in 2019, the accumulation of sandy-shell deposits occurs very quickly, which leads to a reduction in the inflow of sea water. As a result, the water surface area decreases, leading to the drying up of the headwaters, lower reaches, and the right side of the estuary. It is precisely in these areas where the largest number of wetland birds are found, raising concerns about the preservation of their populations and the overall ecological state of the estuary.

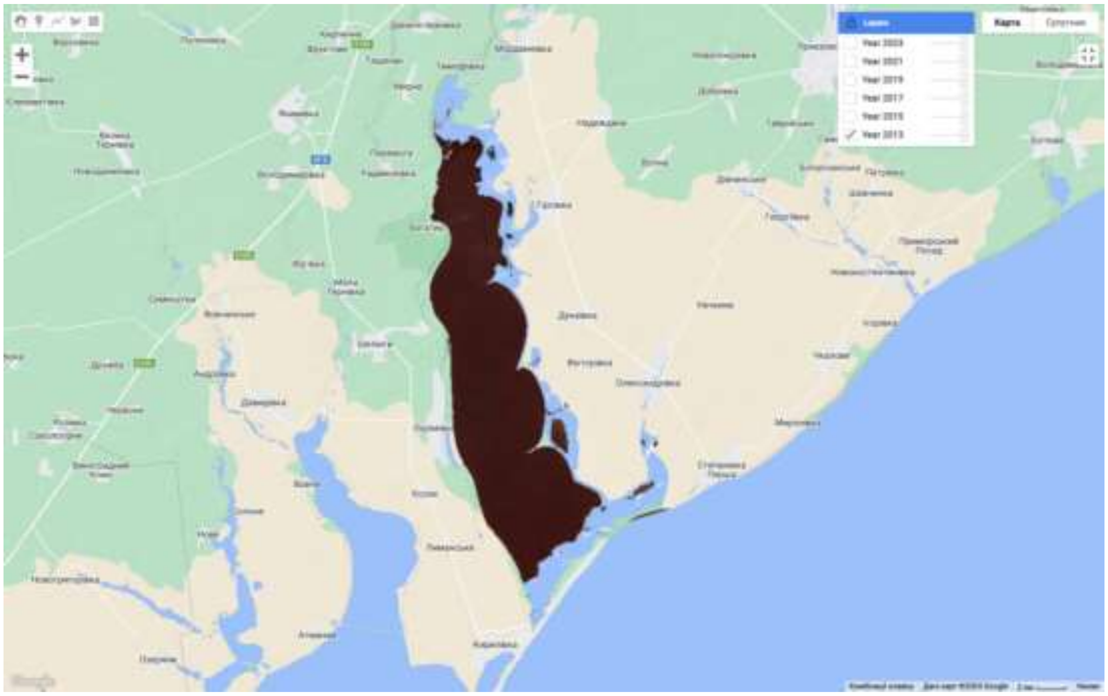

Fig. 11 - Water surface area of Molochnyi Lyman in 2013
The data obtained using the Google Earth Engine software utilized satellite images from Landsat 5, Landsat 8, and Sentinel-2

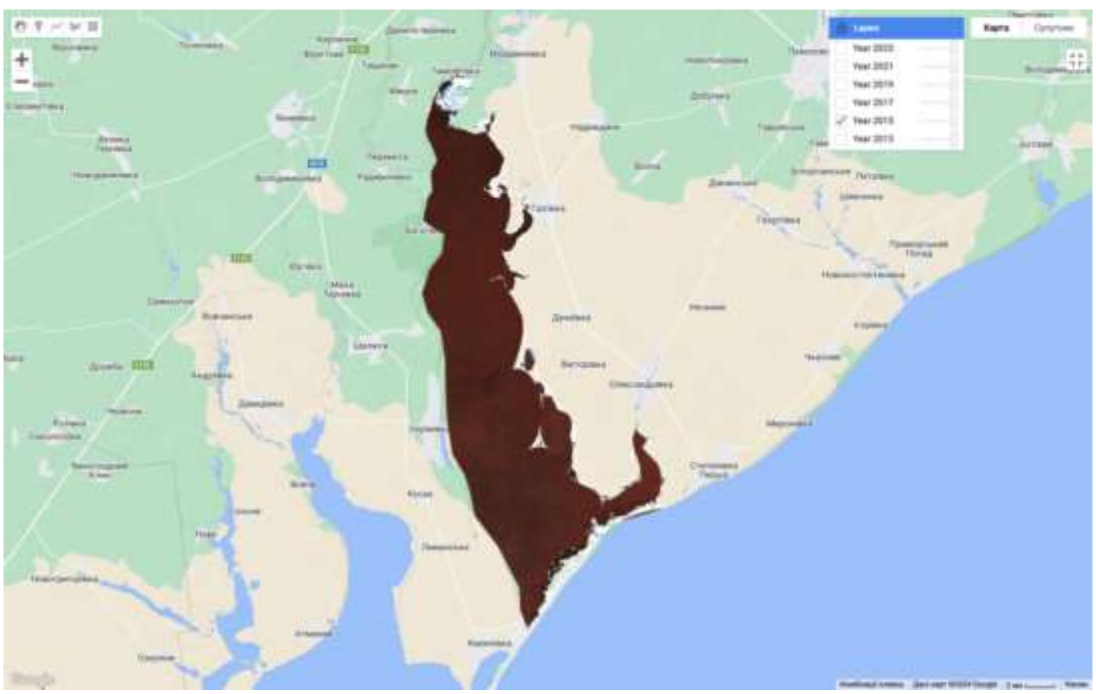

Fig. 12 - Water surface area of Molochnyi Lyman in 2015
The data obtained using the Google Earth Engine software utilized satellite images from Landsat 5, Landsat 8, and Sentinel-2

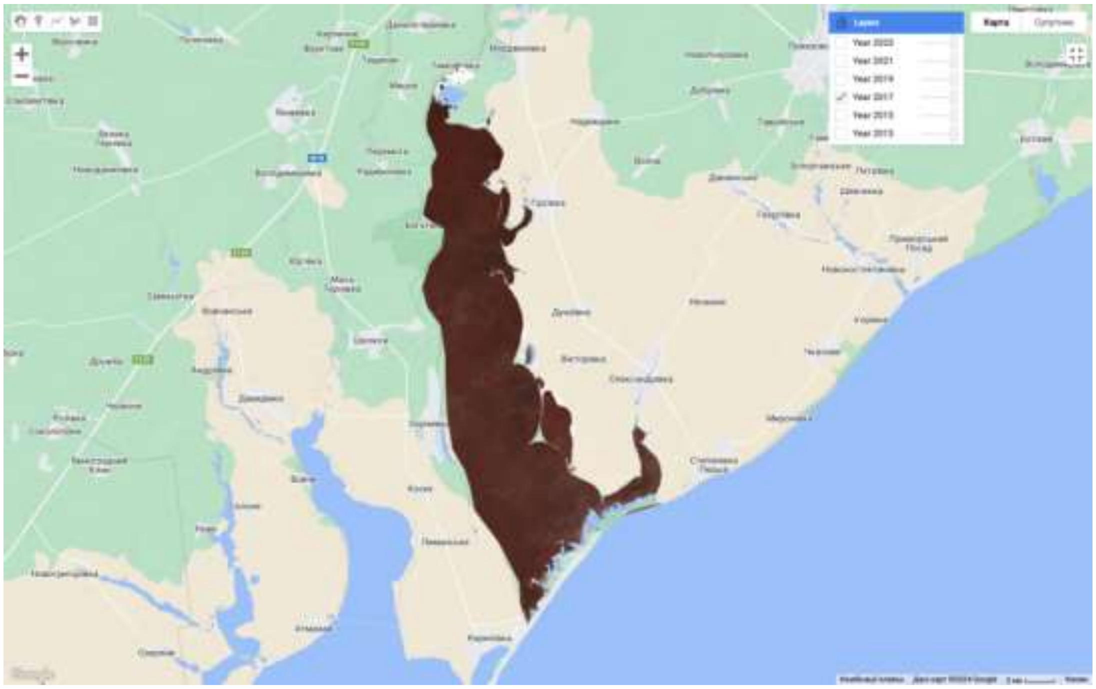

Fig. 13 - Water surface area of Molochnyi Lyman in 2017
The data obtained using the Google Earth Engine software utilized satellite images from Landsat 5, Landsat 8, and Sentinel-2

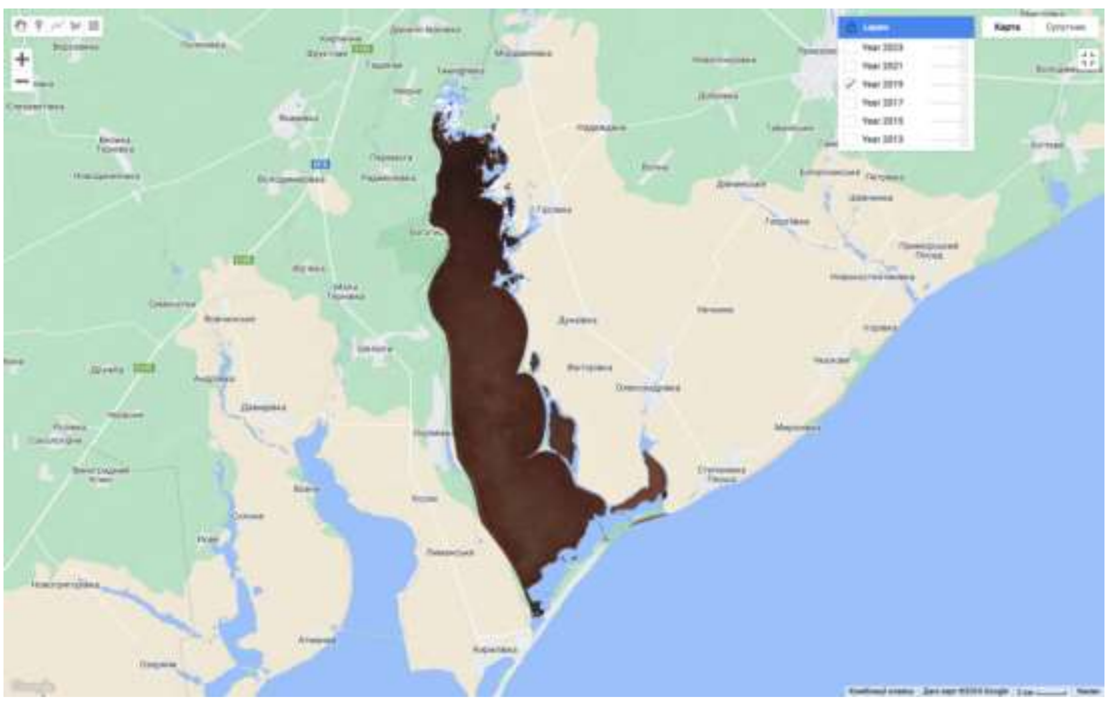

Fig. 14 - Water surface area of Molochnyi Lyman in 2019
The data obtained using the Google Earth Engine software utilized satellite images from Landsat 5, Landsat 8, and Sentinel-2

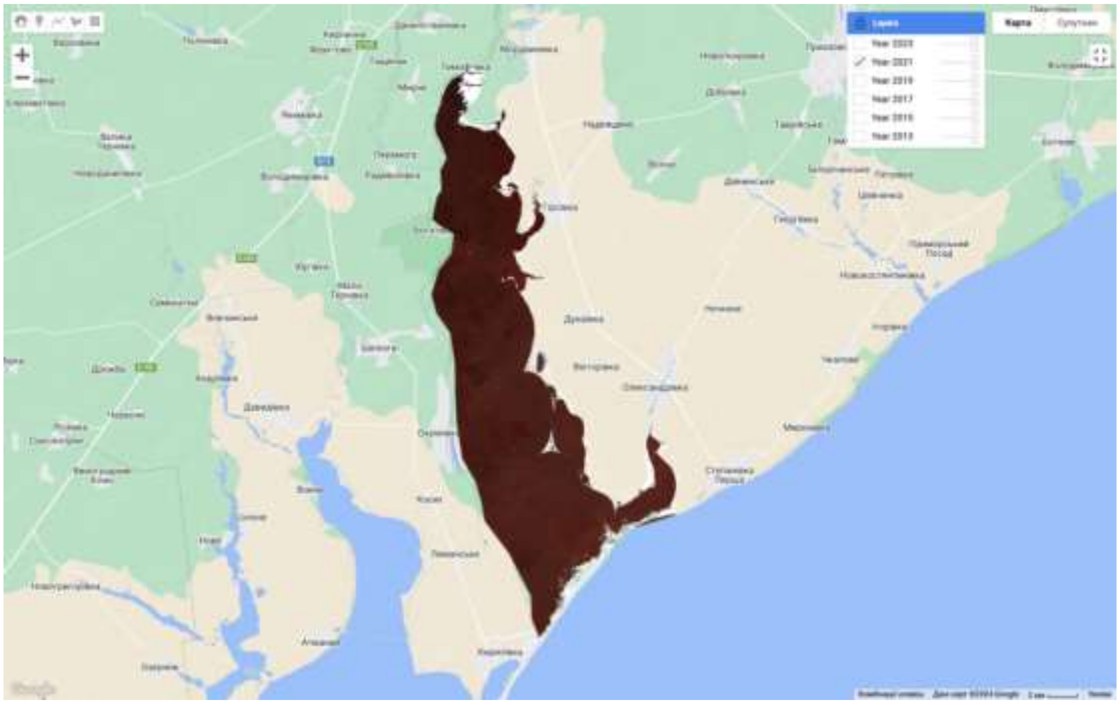

Fig. 15 - Water surface area of Molochnyi Lyman in 2021
The data obtained using the Google Earth Engine software utilized satellite images from Landsat 5, Landsat 8, and Sentinel-2

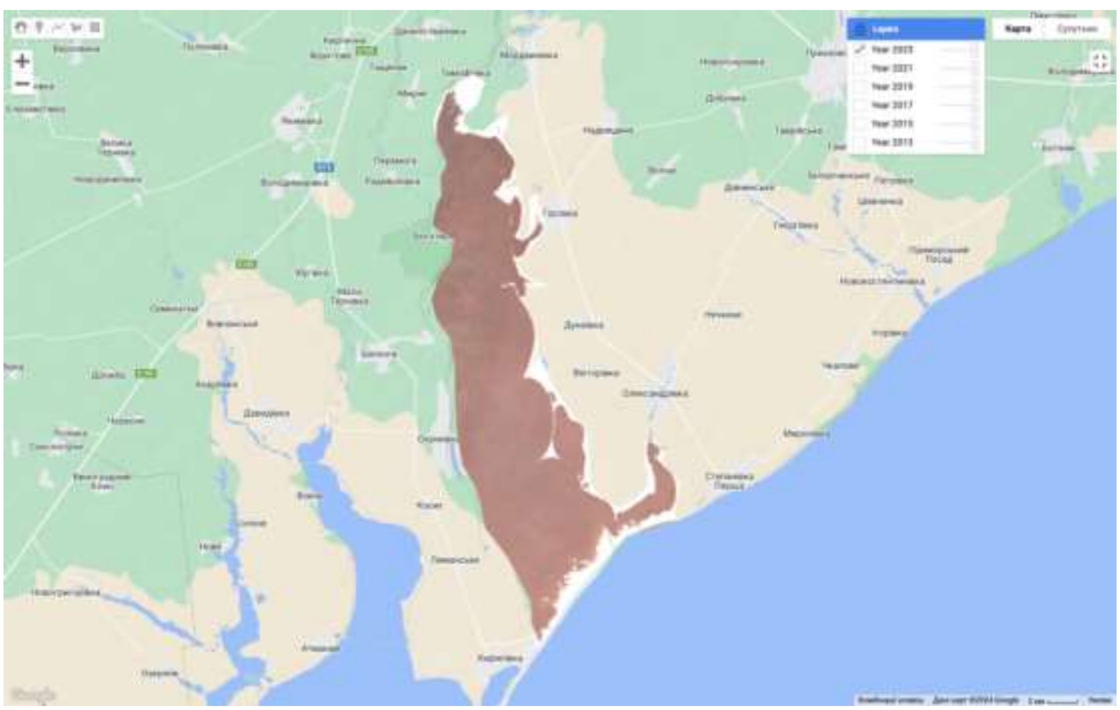

Fig. 16 - Water surface area of Molochnyi Lyman in 2023
The data obtained using the Google Earth Engine software utilized satellite images from Landsat 5, Landsat 8, and Sentinel-2

Conclusions

Molochnyi Lyman is a significant protected area under the Ramsar Convention. The importance of this ecosystem lies in its uniqueness and biodiversity richness. However, due to the reduced inflow of sea water, the estuary is at risk of degradation. The main ecological challenges include increased salinity, reduced water surface area and biodiversity, and the silting of channels connecting the estuary to the Sea of Azov. Preserving the estuary requires stable water exchange and optimal salinity levels, which will ensure favorable conditions for the spawning and migration of fish, as well as maintaining high ecosystem productivity. To ensure a stable ecological state of Molochnyi Lyman, comprehensive water resource management measures are necessary, including regular channel clearing and maintaining an optimal hydrological regime. This will help preserve unique species of flora and fauna and ensure the sustainable development of this protected area.

Due to the accumulation of shell deposits, silting occurs in the channel connecting Molochnyi Lyman with the Sea of Azov. This negatively affects the aquatic and adjacent terrestrial ecosystems, particularly the ornithofauna, as areas used by birds for nesting and meeting their trophic needs disappear. Increased water salinity, turning the estuary into an ultra-haline environment, also negatively impacts aquatic organisms.

The reduction in the water surface area at the head, lower reaches, and the right side of the estuary leads to the drying of these areas, which are the most favorable places for the nesting of wetland birds. Moreover, the silting of the channel disrupts the processes of spawning, migration, and fattening of various fish species, including commercial species. The tendency for rapid silting of the channel even after clearing indicates that simple clearing work is insufficient.

Therefore, it is necessary to develop more effective clearing methods or structures that would slow down the silting process in the long term. More frequent and effective clearing is critically important for preserving this protected area, which holds extraordinary importance according to the Ramsar Convention.

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. Furthermore, the authors have fully adhered to ethical norms, including avoiding plagiarism, data falsification, and duplicate publication.

References

1. Vorovka, V. P., & Demchenko, V. O. (2019). Hydroecological Problems of Dairy Estuary in Connection with the Instable of its Communication with the Azov Sea. *Visnyk of V. N. Karazin Kharkiv National University. Series Ecology*, (21), 23-33. https://doi.org/10.26565/1992-4259-2019-21-02 (In Ukrainian)
2. Vorovka V.P., Demchenko V.O., & Vinokurova S.V. (2015). Dynamics of hydrological indicators of Molochny Liman as a state-level hydrological reserve. *Hydrology, Hydrochemistry, and Hydroecology,* 1(36), 46-56. Retrieved from http://nbuv.gov.ua/UJRN/glghge_2015_1_8 (In Ukrainian)
3. Bondarenko, A.O. (2012). On one of the aspects of the comprehensive solution to the issue of the construction of the Azov Sea - Molochny Liman canal. *Beneficiation of Minerals: Scientific and Technical Collection*, (50(91)), 21-26. Retrieved from https://ir.nmu.org.ua/jspui/handle/123456789/152093?mode=simple (In Ukrainian)
4. Kyrychenko, R.I. (2022). Justification of comprehensive scientific studies of aquatic bioresources in Molochny Liman of the Sea of Azov: Master's thesis: Dnipro State Agrarian and Economic University, Biotechnology Faculty, Department of Aquatic Bioresources and Aquaculture. Dnipro. Retrieved from https://dspace.dsau.dp.ua/handle/123456789/6263 (In Ukrainian)
5. Demchenko, V.O., Chernychko, R.M., Chernychko, Y.I., Dyadicheva, O.A., Koshelev, O.I., & Demchenko, N.A. (2012). Current state of Molochny Liman as a wetland of international importance. *Nature Conservation in Ukraine, 18*(1-2), 114-119. Retrieved from http://eprints.mdpu.org.ua/id/eprint/2185/1/12218.pdf (In Ukrainian)

6. Rubinoff, B. G., & Grosholz, E. D. (2022). Biological invasions alter consumer–stress relationships along an estuarine gradient. *Ecology, 103*(6). https://doi.org/10.1002/ecy.3695
7. Yáñez-Arancibia, A., Lara-Domínguez, A.L., Sánchez-Gil, P., & Day, J.W. (2019). Estuary-sea ecological interactions: a theoretical framework for the management of coastal environments. In K. Withers & M. Nipper (Eds.) *Harte Research Institute for Gulf of Mexico Studies. Special Publication Series No.1.* Corpus Christi (TX): Texas A&M University; (pp. 271-301). Retrieved from https://www.harteresearch.org/sites/default/files/inline-files/14.pdf
8. Largier, J. & Human, L. (2023). Knysna Estuary — Meeting Place of River and Sea. In A.K., Whitfield, C.M. Breen, & M.Read (Eds.) *Knysna Estuary—Jewel of the Garden Route*. (pp. 97-114). Retrieved from https://knysnabasinproject.co.za/wp-content/uploads/2024/01/Chapter-5.pdf
9. Wolanski, E., & Elliott, M. (2015). Estuarine Ecohydrology. An Introduction. Second Edition. Retrieved from https://www.researchgate.net/publication/281119023_Estuarine_Ecohydrology_an_introduction
10. Basic Information about Estuaries. (2024, March 14). *National Estuary Program (NEP).* Retrieved from https://www.epa.gov/nep/basic-information-about-estuaries
11. Why estuaries are important. (2021, December 21). *Environment and Heritage.* Retrieved from https://www2.environment.nsw.gov.au/topics/water/estuaries/about-estuaries/why-estuaries-are-important
12. Oxley, Ch. C., & Jurgens, L. J. (2024). Material type affects the community composition and abundance of hard-substrate assemblages in a sedimentary Atlantic estuary. *MEPS*, *727*, 35-47. https://doi.org/10.3354/meps14497
13. Ivanov, V.M. (2006). Features of the dynamics of hydrological, hydrochemical, and hydroecological indicators of Molochny Liman at the present stage. *Scientific works of UkrNDGMI*, (255), 185-192. (In Ukrainian)
14. Demchenko, V.O. (2011). Fish species of protected categories in water bodies of the north-western part of the Sea of Azov. *Marine Ecological Journal*, *10*(4), 40-49. Retrieved from https://www.researchgate.net/publication/323512412_Ribi_ohoronnih_kategorij_vodojm_pivnicno-zahidnoi_castini_Azovskogo_mora (In Ukrainian)
15. Baraboha, N.M., Yarova, T.A., Antonovsky, O.G., & Tkachenko, V.V. (2019). Results of biodiversity studies in the Azov National Natural Park for the period 2011-2017. Nature Conservation in the Steppe Zone of Ukraine (dedicated to the 50th anniversary of the creation of the Lugansk Nature Reserve, the 70th anniversary of the Striltsivsky Steppe, the 10th anniversary of the Tryokhizbensky Steppe, and the 90th anniversary of the Provalsky Steppe). (10), 33-40. Retrieved from http://eprints.mdpu.org.ua/id/eprint/5429/ (In Ukrainian)
16. Antonovsky, O.G., Tkachenko, V.V., & Onofrash, K.M. (2020). Results of studies of macrozoobenthos in the water areas of the Azov NPP in 2019. Proceedings of the XI scientific-practical conference "Reclamation and water use. Functioning of technical and technological systems". Melitopol, 61-64. (In Ukrainian)
17. Figueroa, D., Capo, E., Lindh, M.V., Rowe, O.F., Paczkowska, J., Pinhassi, J., & Andersson, A. (2021). Terrestrial dissolved organic matter inflow drives temporal dynamics of the bacterial community of a subarctic estuary (northern Baltic Sea). *Environmental Microbiology, 23*, 4200-4213. https://doi.org/10.1111/1462-2920.15597
18. Baraboha, N.M., Yaroviy, S.O., & Baraboha, O.P. (2013). Results of biodiversity inventory in the Azov National Natural Park. *Collection of scientific papers of the State Natural Biosphere Reserve "Biodiversity Inventory within Nature Reserve Fund", 13,* 43-50. (In Ukrainian)
19. Kolomiichuk, V.P. (2002). Floristic and cenotic diversity of the islands of the north-western coast of the Sea of Azov and Sivash. PhD thesis. Kyiv: Institute of Botany named M.G. Holodnyi National Academy of Sciences of Ukraine. Retrieved from http://geobot.org.ua/files/publication/125/kolomijchuk.pdf (In Ukrainian)
20. Bren, O.G., Solonenko, A.M., & Podorozhny, S.M. (2022). Species composition of algae in saline coastal water bodies of the Azov National Park. *Algologia, 32*(1), 68-87. https://doi.org/10.15407/alg32.01.068 (In Ukrainian)
21. Crump, B.C., & Bowen, J.L. (2024). The Microbial Ecology of Estuarine Ecosystems. *Annual Review of Marine Science, 16,* 335-360. https://doi.org/10.1146/annurev-marine-022123-101845
22. Alekseyev, N.A. (1970). Some issues of the hydrochemistry of Molochny Liman. *Proceedings of the All-Union Geographical Society, 102*(47), 382-384. (In Ukrainian)
23. Yankovsky, B.A. (1961). Ichthyofauna of Molochny Liman after its connection with the Sea of Azov. *Scientific Reports of the Higher School*, (3), 44-47. (In Ukrainian)
24. Azov Fish Protection Patrol. (2020, March 13). Retrieved from http://www.azov.darg.gov.ua/index.php?lang_id=1&content_id=765&lp=34 (In Ukrainian)
25. State Statistics Service of Ukraine. (2024, March 29). Retrieved from https://www.ukrstat.gov.ua/operativ/operativ2017/rg/rg_u/arh_dvbr_reg_u.html (In Ukrainian)

26. The salinity level of the Sea of Azov has almost equaled that of the Black Sea. (2023, October 30) Ecopolitics website. Retrieved from https://ecopolitic.com.ua/ua/news/riven-solonosti-azovskogo-morya-majzhe-zrivnyavsya-z-chornim/ (In Ukrainian)
27. State Agency of Ukraine for Development of Melioration, Fisheries, and Food Programs. (2020, July 27). Retrieved from https://darg.gov.ua/_informacija_shchodo_0_1_0_10004_1.html?search=%F1%EE%EB%EE%ED%B3%F1%F2%FC%20%E7%ED%E0%F7%ED%EE%20%EF%E5%F0%E5%E2%E8%F9%F3%EA (In Ukrainian)
28. In Melitopol, the river turned into a stream of white liquid with an unbearable smell. (2023, July 24). Ecopolitics website. Retrieved from https://ecopolitic.com.ua/ua/news/u-melitopoli-richka-peretvorilasya-na-potik-biloi-ridini-z-nesterpnim-zapahom/ (In Ukrainian)

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ЕКОЛОГІЧНІ ЗАГРОЗИ І РИЗИКИ ДЛЯ ПРИРОДООХОРОННИХ ТЕРИТОРІЙ В УМОВАХ ВІЙНИ (НА ПРИКЛАДІ МОЛОЧНОГО ЛИМАНУ)

Мета. Дослідження екологічного стану Молочного лиману, який є заказником загальнодержавного значення, частиною Приазовського національного природного парка, водно-болотним угіддям міжнародного значення, що охороняється згідно Рамсарської конвенції.

Методи дослідження. Системний аналіз, використовано дані дистанційного зондування, зокрема супутникові знімки Landsat 5, Landsat 8, Sentinel-2, а також програмний інструмент Google Earth Engine.

Результати. Надана характеристика біорізноманіття Молочного лиману та проаналізований вплив рівня солоності водойми на стан її біорізноманіття. Проаналізовані природні та антропогенні чинники впливу на екологічний стан Молочного лиману. Особлива увага приділена аналізу умов забезпечення водообміну з Азовським морем та наслідків його відсутності для біорізноманіття водойми. Проведений аналіз стану та динаміки промислового вилову риби у Азовському морі (Запорізька область) та факторів, що впливають на стан рибних ресурсів. Оцінений вплив війни на екологічну ситуацію у Молочному лимані та визначені шляхи та можливості подолання кризових екологічних наслідків окупації території на етапі повоєнного відновлення.

Висновки. Визначені основні екологічні проблеми Молочного лиману: підвищення солоності, зменшення площі водного дзеркала та біорізноманіття, а також замулення каналів, що з'єднують лиман із Азовським морем. Доведено, що збереження лиману вимагає стабільного водообміну та оптимального рівня солоності, що забезпечить сприятливі умови для нересту та міграції риб, а також підтримання високої продуктивності екосистеми. З початком війни ситуація ускладнилась, виникли додаткові екологічні виклики внаслідок бездіяльності, що у подальшому буде потребувати додаткових зусиль для відновлення біорізноманіття Молочного лимана і Азовського моря.

КЛЮЧОВІ СЛОВА: *Молочний лиман, Азовське море, біорізноманіття, екологічна ситуація, солоність води, водообмін, рибні ресурси*

Список використаної літератури

1. Воровка В.П., Демченко В.О. Гідроекологічні проблеми Молочного лиману у зв'язку з нестабільним його сполученням з Азовським морем. *Вісник Харківського національного університету імені В. Н. Каразіна, серія «Екологія»*. 2019. Вип. 21. С. 23-33. DOI: https://doi.org/10.26565/1992-4259-2019-21-02
2. Воровка В.П., Демченко В.О., Винокурова С.В. Динаміка гідрологічних показників Молочного лиману як гідрологічного заказника загальнодержавного значення. *Гідрологія, гідрохімія і гідроекологія*. 2015. Т. 1(36). С. 46-56. URL: http://nbuv.gov.ua/UJRN/glghge_2015_1_8
3. Бондаренко А.О. Про один з аспектів комплексного вирішення питання будівництва каналу Азовське море - Молочний лиман. *Збагачення корисних копалин: Наук.-техн. збірник*. 2012. Вип. 50(91). С. 21-26. URL: https://ir.nmu.org.ua/jspui/handle/123456789/152093?mode=simple
4. Кириченко Р.І. Обґрунтування комплексних наукових досліджень водних біоресурсів у Молочному лимані Азовського моря : магістер. дипломна робота : 207 , Водні біоресурси та аквакультура / Кириченко Руслан Ігорович; наук. керівник Рожков В.В.; Дніпровський держ. аграр.-економ. ун-т , Ф-т біотехнологічний , Каф. водних біоресурсів та аквакультури. Дніпро, 2022. 51 с. URL: https://dspace.dsau.dp.ua/handle/123456789/6263
5. Демченко В.О., Черничко Р.М., Черничко Й.І., Дядічева О.А., Кошелєв О.І., Демченко Н.А. Сучасний стан Молочного лиману як водно-болотяних угідь міжнародного значення. *Заповідна справа в Україні.* 2012. Т. 18. Вип. 1-2. С. 114-119. URL: http://eprints.mdpu.org.ua/id/eprint/2185/1/12218.pdf
6. Rubinoff B. G., Grosholz E. D. (2022). Biological invasions alter consumer–stress relationships along an estuarine gradient. *Ecology*. 2022. Vol.103. N 6. URL: https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/ecy.3695
7. Yáñez-Arancibia A., Lara-Domínguez A.L., Sánchez-Gil P., Day J.W. Estuary-sea ecological interactions: a theoretical framework for the management of coastal environments. January 2019. Coasts and Estuaries (pp. 377-397) URL: https://www.harteresearch.org/sites/default/files/inline-files/14.pdf
8. Knysna Estuary — Meeting Place of River and Sea. Knysna Estuary—Jewel of the Garden Route С. 97-114. URL: https://knysnabasinproject.co.za/wp-content/uploads/2024/01/Chapter-5.pdf
9. Wolanski E., Elliott M. Estuarine ecohydrology. An Introduction. Second Edition. URL: https://books.google.com.ua/books?id=HRZ0AwAAQBAJ&lpg=PP1&ots=UIMZeEJJP_&dq=connecting%20the%20estuary%20with%20the%20sea&lr&hl=uk&pg=PP1#v=onepage&q=connecting%20the%20estuary%20with%20the%20sea&f=false
10. Basic Information about Estuaries. *National Estuary Program* (NEP). 2024. URL:https://www.epa.gov/nep/basic-information-about-estuaries
11. Why estuaries are important. *Environment and Heritage.* 2021. URL: https://www2.environment.nsw.gov.au/topics/water/estuaries/about-estuaries/why-estuaries-are-important
12. Oxley, Ch. C., Jurgens, L. J. Material type affects the community composition and abundance of hard-substrate assemblages in a sedimentary Atlantic estuary. *MEPS.* 2024. *Vol.*727. P.35-47. DOI: https://doi.org/10.3354/meps14497
13. Іванов В.М. Особливості динаміки гідрологічних, гідрохімічних та гідроекологічних показників Молочного лиману на сучасному етапі. *Наукові праці УкрНДГМІ*, 2006, Вип. 255. С. 185-192.
14. Демченко В.О. Риби охоронних категорій водойм північно-західної частини Азовського моря. *Морський екологічний журнал.* 2011. Т. 10. №4. С. 40-49. URL: https://www.researchgate.net/publication/323512412_Ribi_ohoronnih_kategorij_vodojm_pivnicno-zahidnoi_castini_Azovskogo_mora
15. Барабоха Н.М., Ярова Т.А., Антоновський О.Г., Ткаченко В.В. Результати дослідження біорізноманіття Приазовського національного природного парку за період 2011-2017 роки. Заповідна справа у Степовій зоні України (до 50-річчя створення Луганського природного заповідника, 70-річчя Стрільцівського степу, 10-річчя Трьохізбенського степу і 90-річчя Провальського степу) (10). С. 33-40. URL: http://eprints.mdpu.org.ua/id/eprint/5429/
16. Антоновський О.Г., Ткаченко В.В., Онофраш К.М. Результати досліджень макрозообентосу в акваторіях Приазовського НПП у 2019 році. *Матеріали XI-ої науково-практичної конференції «Меліорація та водовикористання. Функціонування техніко-технологічних систем».* Мелітополь, 2020. С. 61-64.

17. Figueroa D., Capo E., Lindh M.V., Rowe O.F, Paczkowska J., Pinhassi J., Andersson A. 2021. Terrestrial dissolved organic matter inflow drives temporal dynamics of the bacterial community of a subarctic estuary (northern Baltic Sea). *Environ. Microbiol*. Vol. 23. P.4200–4213. DOI: https://doi.org/10.1111/1462-2920.15597
18. Барабоха Н.М., Яровий С.О., Барабоха О.П. Результати інвентаризації біорізноманіття Приазовського національного природного парку. *Збірник наукових праць ДНБС "Інвентаризація біорізноманіття в межах природно-заповідного фонду*". 2013. Т. 13. С. 43-50.
19. Коломійчук В.П. Флористична та ценотична різноманітність островів північно-західного узбережжя Азовського моря та Сиваша. Автореферат дисертації на здобуття наукового ступеня кандидата біологічних наук. 2002. URL: http://geobot.org.ua/files/publication/125/kolomijchuk.pdf
20. Брен О.Г., Солоненко А.М., Подорожний С.М. Видовий склад водоростей солоних приморських водойм Приазовського національного парку. *Algologia* 2022. Vol.32. N1. P. 68–87. URL: https://algologia.co.ua/journal/article/view/32.1.68/33
21. Crump B.C., and BowenJ. L. The Microbial Ecology of Estuarine Ecosystems. *Annual review of marine science*, 2024. Vol. 16. P. 335 - 360. DOI: https://doi.org/10.1146/annurev-marine-022123-101845
22. Алексєєв Н.А. Деякі питання гідрохімії Молочного лиману. *Вісті Всесоюзного географічного товариства,* Т. 102, № 47, С. 382-384, 1970.
23. Янковський Б.А. Іхтіофауна Молочного лиману після його з'єднання з Азовським морем. *Наукові доповіді вищої школи*. 1961. № 3. С. 44-47.
24. Азовський рибоохоронний патруль. URL: http://www.azov.darg.gov.ua/index.php?lang_id=1&content_id=765&lp=34
25. Державна служба статистики України. URL: https://www.ukrstat.gov.ua/operativ/operativ2017/rg/rg_u/arh_dvbr_reg_u.html
26. Рівень солоності Азовського моря майже зрівнявся із Чорним морем. Сайт Екополітика. URL: https://ecopolitic.com.ua/ua/news/riven-solonosti-azovskogo-morya-majzhe-zrivnyavsya-z-chornim/
27. Державне агентство України з розвитку меліорації, рибного господарства та продовольчих програм. URL: https://darg.gov.ua/_informacija_shchodo_0_1_0_10004_1.html?search=%F1%EE%EB%EE%ED%B3%F1%F2%FC%20%E7%ED%E0%F7%ED%EE%20%EF%E5%F0%E5%E2%E8%F9%F3%EA
28. У Мелітополі річка перетворилася на потік білої рідини із нестерпним запахом. Сайт Екополітика. URL: https://ecopolitic.com.ua/ua/news/u-melitopoli-richka-peretvorilasya-na-potik-biloi-ridini-z-nesterpnim-zapahom/

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