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CATASTROPHIC ANTHROPOGENIC VEGETATION CHANGES IN THE KILIYAN ARM OF THE DANUBE DELTA (UKRAINE)

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Background. Delta areas are unique natural ecosystems, characterized by a high diversity of habitats. At the beginning of the previous century, natural complexes of the Danube Delta underwent significant anthropogenic transformations. Large-scale anthropogenic pressure on natural ecosystems of the delta leads to a catastrophic alteration of the ecological regime and degradation of native flora complexes and plant communities. Catastrophic large-scale changes occurred in the last decades as a result of the damming of the riverbed and near-channel ridges of individual islands, and floodplain territories and their subsequent de-damming, the construction of the large-scale deep-water Danube–Black Sea shipping canal, the transformation of significant areas of delta into agricultural land, pulp backfilling of islands and shallow waters. The coastal ecosystems of the eastern part of the Kiliyan arm of the Danube Delta have also been catastrophically impacted by the Russian military actions, mainly caused by explosions of military shells.

Materials and Methods. Long-term comparative phytocoenotic surveys and stationary studies were used in this research. The investigation of the anthropogenic dynamics of vegetation were carried out by direct methods – on stationary and semi-stationary sites. We compared data obtained prior to the construction of the deep-water Danube–Black Sea shipping canal and the recent data obtained after the transformation. The direct methods included the method of comparing the current state with historical maps and geobotanical relevés published in the monograph «Reserve "Wetlands of the Danube"» (Shelyag-Sosonko & Dubyna, 1984).

Results and Discussion. The paper highlights the detected catastrophic anthropogenic vegetation changes based on long-term comparative phytocoenotic surveys and stationary studies. Catastrophic changes in the vegetation of the Danube Delta most pronounced on the territory of Stentsivsko-Zhebryansky floodplain, the Zhebryansk seaside ridge, Yermakov, Mashenka, Katenka, Kislytsky, Maly and Velyky Tataru, Velyky and Maly Dallery islands, in the area of Izmail and Ust-Dunaisk ports, the floodplain zone near the city of Kilya, and most of the floodplain terrace from Vylkovo to Izmail. The most endangered are meadow and psammophyte vegetation with representatives of the psammophilous-littoral neoendemic floristic complex. The floodplain forests are also subject to digression. Only aquatic ecosystems are more labile to hydrological changes.

Conclusion. A strategy for optimizing the vegetation cover of the delta is offered. The established patterns can be used to develop methods for assessing the risks for ecosystems, and the intensity of their degradation to ensure effective protection, management, and sustainable use of the biodiversity in the delta areas of the Northern Black Sea region.

Keywords: anthropogenic transformation, catastrophic changes, plant communities, Danube Delta, Ukraine

INTRODUCTION

Delta areas are unique natural ecosystems characterized by a high diversity of habitats and extremely important from an ecological and an economic point of view (Newton *et al*., 2014). However, they are very vulnerable and sensitive to anthropogenic influences (Syvitski & Saito, 2007). The delta ecosystems of the Northern Black Sea region are characterized by a high diversity of ecosystems and geocomplex dynamism. The dynamism of environmental factors, in particular of alluvial processes, is the main feature of delta biotopes (Dubyna *et al*., 2003).

Large-scale anthropogenic pressure on natural ecosystems of the delta leads to a catastrophic alteration of the ecological regime and degradation of native flora complexes and plant communities. The consequences of an increased anthropogenic influence are the impoverishment of species diversity, phytoinvasion of adventive species, formation of synanthropic communities, and, sometimes, a complete destruction of the original vegetation (Dubyna *et al*., 2003). In this regard, the study of the anthropogenic influence of the Danube Delta is important. The formation and functioning of the vegetation of the anthropically altered territories of delta regions attracted the attention of many researchers. In the Danube Delta, which is located on the territory of two countries, Romania and Ukraine, vegetation dynamic was studied by Ukrainian (Shelyag-Sosonko & Dubyna, 1984; Klokov & Diachenko, 1993; Diachenko, 2010) and Romanian (Godeanu, 1976; Oosterberg *et al*., 2000; Anastasiu *et al*., 2011; Doroftei *et al*., 2011; Trifanov *et al*., 2018) scientists. The aim of this work is to identify the features of catastrophic large-scale anthropogenic changes in the vegetation cover of the Kiliyan arm of the Danube Delta in order to solve problems of biodiversity conservation.

The beginning of the research coincided with the drastic transformations of the Ukrainian part of the Kiliyan arm of the Danube Delta about 50 years ago. The continuation of the work was connected with the construction of the Danube–Sasyk channel and Danube–Black Sea shipping canal; the damming of Yermakov and Maly Tataru islands. It is obvious that the modern anthropogenic impact on geocomplexes of the Kiliyan arm

of the Danube Delta is the greatest in history. Therefore, recognition and monitoring of changes is recommended. This will contribute to minimizing the negative impact of anthropogenic transformations, and provide for sustainable use of plant resources of this unique and historically young territory.

The Danube Delta begins to the southwest of the city of Izmail, at the place where the Danube River divides into two branches: the Kiliyan estuary and the Tulchynsky estuary. The Tulchynsky arm, 17 km downstream, branches into the Georgiev and Sulina estuaries, which flow into the Black Sea separately and are located on the territory of Romania. The Kiliyan arm, which is the most flooded, is located on the territory of Ukraine and flows into the Black Sea southeast of the town of Vylkovo (**Fig. 1**).

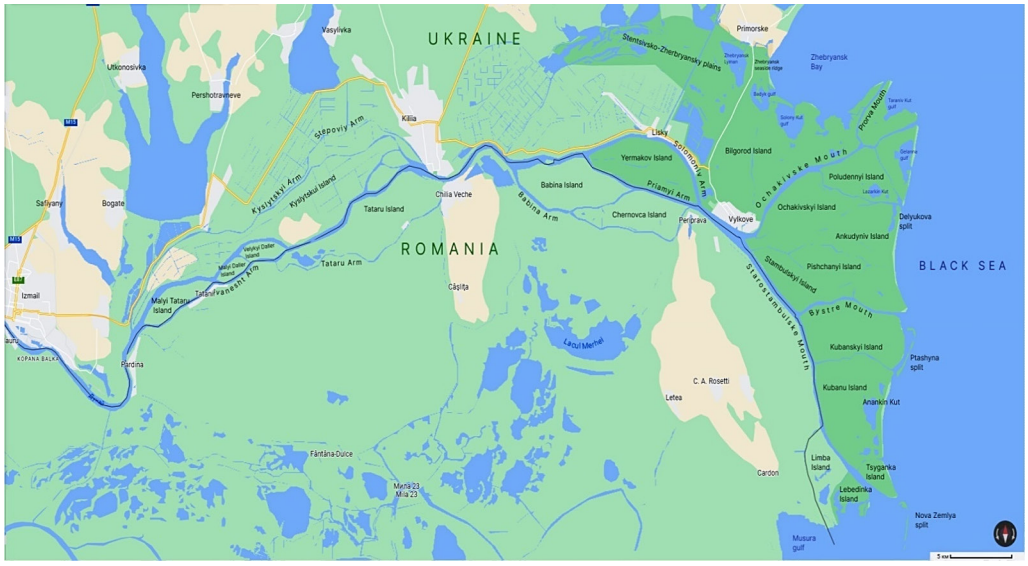

Fig. 1. Map of the studied territory

The border between Ukraine and Romania runs along it. The length of the Kiliyan arm is 116 km, the width is up to 1.2 km. On the Izmail–Vylkovo section, it branches twice and reunites twice into one stream, forming a primary (internal) delta and a secondary (external) delta. A second delta is formed below the town of Vylkovo. Here the channel is divided into the main branches: Ochakivsky (left) and Starostambulsky (right). The area of the Kiliyan arm of the Danube Delta is 1200 km² and is constantly increasing due to alluvial deposits. The lower part of the estuary is located within the Danube Biosphere Reserve with an area of 50252.9 hectares. It is part of the bilateral Romanian-Ukrainian Danube Delta Biosphere Reserve, one of the five bilateral reserves in the world (Dubyna *et al*., 2003). The Danube Biosphere Reserve is included in the UNESCO World Network of Biosphere Reserves. The wetlands of the Kiliyan arm of the Danube Delta were included in the List of Wetlands of International Importance under the Ramsar Convention in 1995. According to the geomorphological structure, it is a lowland flat alluvial and alluvial-estuarine plain, slightly dissected by gullies, which is quite typical of large deltas of the Eurasian continent, characterized by low and flat territories. About 87 % of the delta area is occupied by floodplains with a depth of 1–2, less often 3–4 m. The delta is swampy, covered by a dense network of inlets and lakes. On the territory of the delta,

alluvial, meadow and meadow-swamp, swamp, sod-glazed soils and salt marshes are common (Mazur *et al.*, 2011). The surface of the territory is almost horizontal, divided into short-, medium-, and long-flooded areas according to the duration of the flood regime. Alluvial ridges and dunes are formed along watercourses. Dunes are the remnants of geosystems, the formation of which took place on the former sea borders of the delta. There are also artificial elevations in the delta – dams, ramparts, and alluvial (as a result of the deepening of watercourses) islands. The coast of the delta is shallow and characterized by unstable channel furrows. The climate of the Danube Delta is moderately continental with hot, dry summers and mild, unstable winters with little snow. The average monthly temperature in July is 22.5–23.0 °C, and in January – 2.0 °C. Average annual precipitation is 350–400 mm with an average annual evaporation of 800–900 mm. Winter is characterized by thaws, and snow cover does not form every year.

MATERIALS AND METHODS

The studies were carried out during 1973–2023 in the Kiliyan arm of the Danube Delta. Long-term comparative phytocoenotic surveys and stationary studies were used in this research. The studies of the anthropogenic dynamics of vegetation were carried out by direct methods – on stationary and semi-stationary sites, as well as by indirect methods. We also used data about the wildlife which was collected by the staff of the nature reserve “Wetlands of the Danube” from the moment of its creation. We compared data collected before the construction of the deep-water Danube–Black Sea shipping canal and recent data obtained after the transformation. This review, based on the long-term personal and literature data, will make it possible to highlight the leading anthropogenic factors and take action for the further restoration of the ecosystems of the Danube floodplain.

The direct methods included the method of comparing the current data with historical maps and geobotanical relevés presented in the monograph «Reserve ”Wetlands of the Danube”» (Shelyag-Sosonko & Dubyna, 1984). Indirect methods included the reconstruction of successive trends based on the analysis of ecological and coenotic profiles.

Names of the species are given according to the “Nomenclatural Checklist of the Vascular Plants of Ukraine” (Mosyakin & Fedoronchuk, 1999), syntaxon names correspond to those given in the “Prodrome of the Vegetation of Ukraine” (Dubyna *et al.*, 2019).

RESULTS AND DISCUSSION

The vegetation of the Kiliyan arm of the Danube Delta is coenotically rich, which is determined by the climatic features of the region and the diversity of ecological conditions. On a relatively small area, landscapes from semi-deserts to wetlands are presented. This causes the abundance of different types of vegetation: aquatic, marsh, wetland, meadow, halophytic, forest, and psammophytic. The plant cover of this region has a higher amount of aquatic and swamp communities compared with the phytosystems of other large delta areas in the Northern Black Sea region. They occupy about 80 % of the area. Halophytic and meadow vegetation occupy relatively smaller areas (approximately 10 %) (Dubyna *et al.*, 2003). The majority of phytocoenoses are intrazonal. The main factors determining their territorial peculiarities are the character and intensity of interaction between the watercourses of the Danube and the sea. They develop under specific conditions of the presence of large aquatic areas, the washing regime of the Danube’s arms, and the wind downsurge and upsurge (**Fig. 2**).

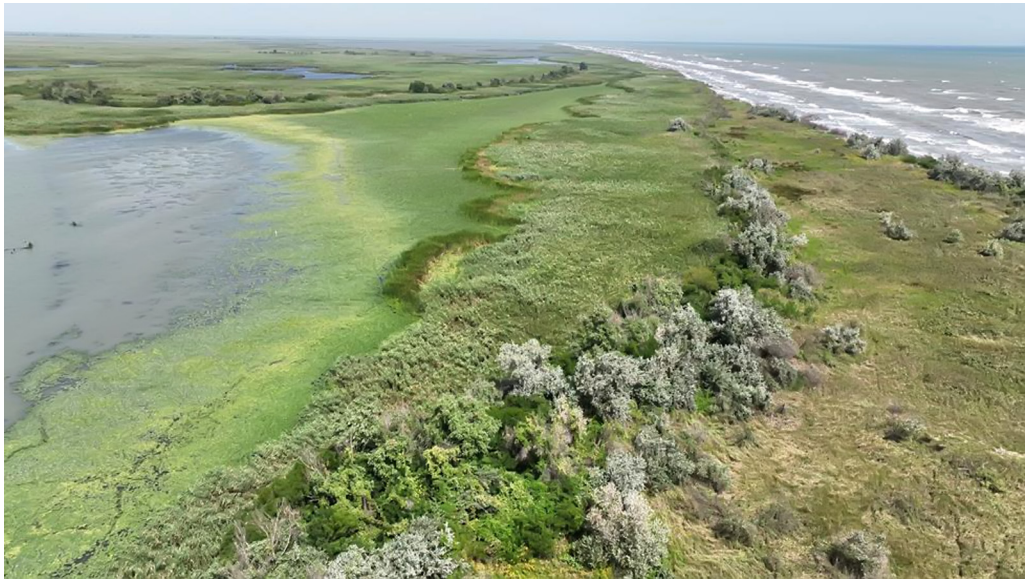

Fig. 2. Landscapes of the seaside part of the Kiliyan arm of the Danube Delta

They include many rare and endangered communities listed in the Green Data Book of Ukraine (Didukh, 2009b). In particular, *Aldrovandetum vesiculosae, Trapetum natantis, Batrachietum rionii, Nymphaeo albae-Nupharetum luteae, Schoenoplectetum litoralis, Ceratophylletum tanaitici, Ceratophylletum submersi, Potameto natantis-Nupharetum luteae, Nymphoidetum peltata, Potametum sarmatici, Lemnetum gibbae, Lemno-Salvinietum natantis,* and *Butomo-Sagittarietum sagittifoliae.*

Catastrophic anthropogenic changes in vegetation. Anthropogenic changes in the vegetation of the Danube Delta are spread and most pronounced on the territory of Stentsivsko-Zhebryansky floodplain, the Zhebryansk seaside ridge, Yermakov, Mashenka, Katenka, Kislytsky, Maly and Velyky Tataru, Velyky and Maly Dallery islands, in the area of Izmail and Ust-Dunaisk ports and the floodplain zone near the city of Kiliya, as well as the coastal areas of the islands of Bilhorodskyi, Poludennyi Istanbulskyi, etc. (secondary delta) and most of the floodplain terrace from Vylkovo to Izmail. According to the nature of the changes, the most spread are catastrophic large-scale changes (changes caused by large-scale hydro-technical constructions, changes due to reclamation of islands, construction of ponds and checks, pulp backfilling of islands and shallow waters). Recently the new catastrophic threat has appeared, mainly, caused by explosions of military shells.

Changes caused by large-scale hydro-technical constructions. Catastrophic changes of vegetation are a result of large-scale hydro-technical construction leading to irreversible losses of plant cover and the formation of communities with modified species composition. They include construction of channels (Danube–Black Sea, Danube–Sasyk), deepening and damming of the Sulina estuary.

The dredging of the Sulina deep-sea shipping channel (Romania) and the construction of two parallel protective dams (breakwaters) in its lower reaches, the length of which in the Black Sea is already about 13 km, had a most significant and transforming

anthropogenic impact on the natural complexes of the Danube Delta. Their construction led to the blocking of the Old Istanbul estuary, which was the most powerful waterway in the past. This process caused significant changes in the organization of the most active part of the Danube Delta. There is a large-scale redistribution of the flow, which has already been changed due to the construction of the Danube–Black Sea Canal, as well as the construction of a stream-directing dam (above the city of Izmail), the straightening of the Georgievsky and deepening of the Sulinsky (Romania) arms.

Construction of the Danube–Black Sea shipping canal and the formation of the Ptashyna Spit altered the biogenetic channel of the Kiliyan arm of the Danube Delta, in particular, in its coastal-island part. This channel promoted the exchange of genetic material between the coastal-littoral regions of the Western and Northern Black Sea coast, primarily in the psammophilic-littoral neoendemic floristic complex. The reduction of landscape diversity impedes the natural processes of species formation.

Ukraine has been carrying out this transport project since 2003 to restore navigation through the Kiliyan and Novostambulsky (Bystre) estuaries in the Danube Delta. The Danube–Black Sea Canal has a total length of 170.36 km and a draft of about 6.5 m. The hydrotechnical construction work, in particular, dams along the left bank of the Novostambulsky estuary, the embankment and undamming of Yermakov Island, the operation of the Danube–Black Sea Canal, and the annual deepening of its coastal part, led to systemic transformations of landscapes and, accordingly, functioning of biodiversity. The original floristic and coenotic complexes underwent a significant transformation. The operation of the Danube–Black Sea Canal poses great problems since it is almost impossible to minimize its negative impacts or restore the transformed ecosystems.

With the formation of the Ptashyna Spit and the creation of the Bystry Bay, the accumulative processes of the delta formation were stopped. This has caused erosion of the coastline of Kuban Island and changes in its vegetation. Coenoses of shrub vegetation have been gradually overgrown with grasses of a wide ecological amplitude (*Calamagrostis epigeios, Phragmites australis, Elytrigia repens*) and with adventive (*Anisantha tectorum, Echinochloa crus-galli, Ambrosia artemisiifolia, Bidens frondosa, Conyza canadensis, Carduus acanthoides, Xanthium albinum, Digitaria sanguinalis, Atriplex prostrata, Artemisia absinthium, Sonchus arvensis, Lactuca serriola,* etc.) species. Under these conditions, the psammophytic endemic complex, whose representatives disappeared, underwent the greatest negative impact. First of all, populations of *Melilotus arenarius, Lythrum melanospermum, Agrostis maeotica, Polygonum hypanicum, Rumex halacsyi, Asperula setulosa,* and *Centaurea majorovii* were transformed.

The development of coastal florocenotic complexes has also been subject to great transformation. At this stage, the gradual erosion of elevated landforms and the absence of a successional stage that represents shrub vegetation, common for other coastal spits of the Kiliyan arm, were noted. This erosion significantly affects coastal parts of the Ptashyna Spit. Due to the rolling of waves through the elevated areas, the latter fall under a constant, uncharacteristic, alluvial influence. Therefore, the plant cover undergoes alluvial selection and is characterized by poor floristic composition. Processes of fixation of newly formed soils are slow. They are also subject to water erosion, even during rain, which is not typical. In the future, the speed of migration of alluvial sediments of the Ptashyna Spit in the direction of the coastline of Kubansky Island will accelerate. Thus, the natural vegetation, characteristic of newly formed coastal spits will, probably, not develop. The northeastern part of the Kiliyan arm is characterized

by the absence of salinity. It means that stagnation of alluvial activity will lead to the formation of vegetation like the coenoses of transformed areas in the Ust-Dunaisk port (Prorvyn estuary) with certain modifications (Dubyna *et al*., 2003).

The eastern coast of Ptashyna Spit is colonized by many birds, therefore the local coenoses are formed by nitrophilous species of a wide ecological amplitude. Such coenoses are characterized by high productivity, but a poor floristic composition (from 3 to 7 vascular plants) and a simple coenotic structure (**Fig. 3**).

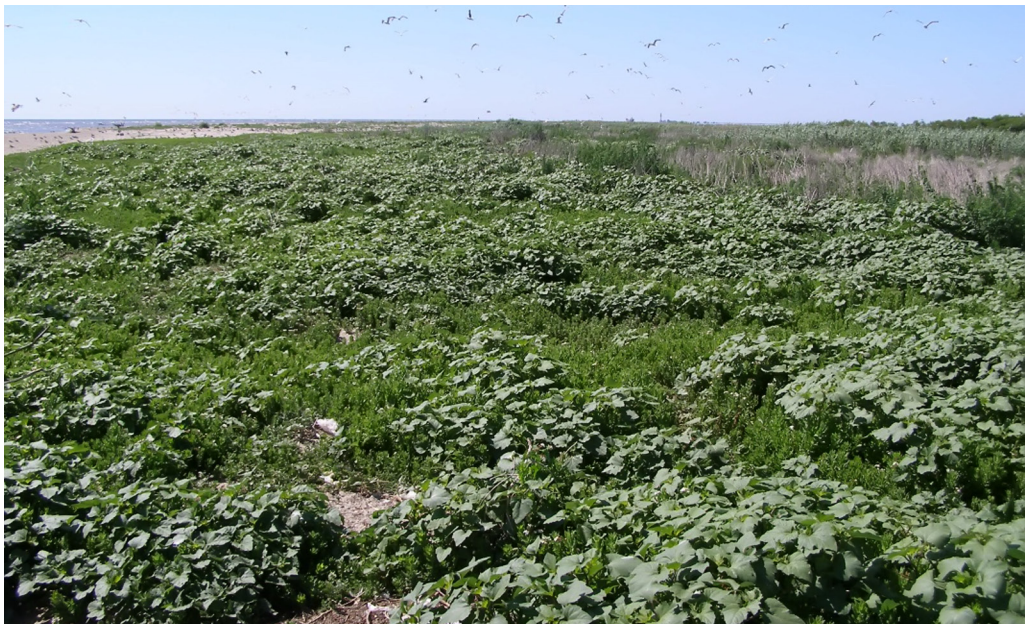

Fig. 3. Nitrophylous vegetation of the Ptashyna Spit with dominance of *Xanthium albinum* and *Argusia sibirica*

As a result of the weak development of the vegetation cover, erosion of some sections of the spit occurs. In the absence of vertical growth of the spit and, accordingly, due to the minimization of accumulative abrasive processes blocked by the silts of the Sulina deep-sea channel, the expansion of alien species increased. Transformer species, which have a high invasive potential and can naturalize at the phytocoenotic level, through the active and intensive renewal of populations, represent a special danger (Protopopova, 1991; Protopopova *et al*., 2002). Results of the monitoring show that Ptashyna Spit has the biggest areas covered by adventive transformer species (*Xanthium albinum, Conyza canadensis, Centaurea diffusa, Ambrosia artemisiifolia, Brachyactis ciliata*). The threat of phytoinvasion is exacerbated by the fact that diasporas of alien species new to Ukraine constantly enter the spit with ballast waters. In a short period of time, they are able to occupy significant coastal areas, diminishing the position of aboriginal alluviophyte species and changing the direction of dynamic processes in coastal areas (Anastasiu *et al*., 2011). They are represented by *Diplachne fascicularis* and *Eclipta prostrata*. In the territory of the Danube Delta *Acer negundo*, *Amaranthus retroflexus*, *Amorpha fruticosa*, *Cardaria draba, Conium maculatum, Elaeagnus angustifolia*, *Hordeum leporinum*, *H. murinum*, and *Solidago canadensis* also belong to species with high invasiveness.

In the Novostambulsky (Bystry) Bay the deepening of the channel for shipping, speeding of the current and the removal of sediments into the sea led to an increasing of shallow waters in the adjacent area by 104.9 ha and to the formation of spits and small islands on an area of 29.5 ha.

The vegetation of the Bystry Bay is currently represented by separate fragments of aquatic vegetation. Formation of typical vegetation belts does not occur. It is caused by rapid shallowing and excessive deposition of sediment. If the processes of rise of the bottom surface accelerate, we should expect a massive development of vegetation dominated by *Butomus umbellatus, Sagittaria sagittifolia, Alisma plantago-aquatica, Oenanthe aquatica, Scirpus tabernaemontanii,* etc. According to our observations, in a span of 5 years, they completely occupied the former aquatic area of the Bystry Bay. In the future, these coenoses will be replaced by wetland vegetation and with an increase in salinization processes and a decrease in water exchange – by saline meadows.

The construction of the sea dam radically changed the water regime of the coastal-island part of Starostambulsky Island. The impact of the accumulation and denudation activity of the sea sharply decreased due to the formation of a large shallow area, the southern part of which is outlined by a sea spit. In the first year of construction, in August and September, a massive development of multicellular algae of the genus *Cladophora* was observed in shallow waters, which was not typical of these areas before the hydro-technical works. In connection with decreasing alluvial processes, the accelerated formation of underwater geomorphostructures and their overgrowth by aquatic vegetation of wide ecological amplitude was discovered. Their appearance and mass distribution are a trigger for future negative processes. These processes will completely neutralize the accumulative-denudation impact on the seaside geocomplexes of Starostambulsky Island. Fixing the dam and its extension into the sea will change the coastline of the island. The formation of vegetation belts will slow down and stop completely. In particular, the formation of shrub vegetation dominated by *Hippophae rhamnoides* will not occur. Also, the formation of the coastal ridge and, accordingly, the formation of the littoral geocomplex, which is characterized by a wealth of neo-endemic species, will be suspended. The coastal ridges and other elevated areas transform as a result of epeirogenic processes. Their overgrowth with tall grass species of wide ecological amplitude, which is now observed on Kubansky Island, will significantly suppress the vitality of existing communities. The number of endemic species will decrease. Salinization processes will increase in depressions causing the formation of low-species communities of salty marshes. Meadow and meadow-steppe coenoses will be replaced by saline meadows and salt marshes, respectively.

The vegetation of Lebedynka and Limba islands is under anthropogenic pressure. First of all, changes occurred in the composition of swamp vegetation which is represented by rare and disappearing coenoses of the Azov-Black Sea region. Unique complexes of shrub swamps, which migrated from the north during the glaciations and adapted to new conditions in the coastal zone (Dubyna *et al*., 2003), are currently degrading under the influence of water regulation. Changes caused by the implemented water regulating influence also occur in the composition of aquatic vegetation, which plays an important ecological role in the region. The growth of eutrophication processes caused a massive development of algae, which was not characteristic in this part.

It should be noted that the large-scale hydro-technical construction caused a significant anthropogenic transformation of the vegetation cover also in the southern part

of the Kiliyan arm of the Danube Delta on the Nova Zemlya Spit. The main geomorphostructures of the Nova Zemlya Spit form as a result of abrasion-accumulation and deflation processes activated after dredging of the Sulina deep-sea shipping channel. The length of the spit already exceeds 8 km. The southern part of it has already reached Romania and continues further on its territory. Under such conditions, the formation of the original landscape and biological diversity does not occur. The coastal ridge and, accordingly, the psammophytic coenoses are not formed. In general, hygromesophytic pioneer vegetation, presented by *Amorpha fruticosa*, prevails.

We do not agree with the conclusion of Ukrainian hydrobiologists about the absence of negative impact of deep-sea shipping on adjacent ecosystems in the Kiliyan arm of the Danube Delta (Liashenko *et al*., 2022). Perhaps aquatic ecosystems are more labile to hydrological changes, but terrestrial complexes are more vulnerable. In addition, the long-term consequences of this large-scale hydro-technical construction must be considered. It is obvious that the formation of the Ptashyna Spit and the Bystra Bay put unique endemic florocenotic complexes under the threat of extinction.

Changes due to reclamation of islands, construction of ponds and paddy fields. The hydro-technical construction of the 14-km long Danube–Sasyk Canal with the embankment of floodplain areas and the division of the Stentsivsko-Zhebryansky floodplains into two parts in 1978 led to catastrophic changes in the vegetation cover of this territory (**Fig. 4**).

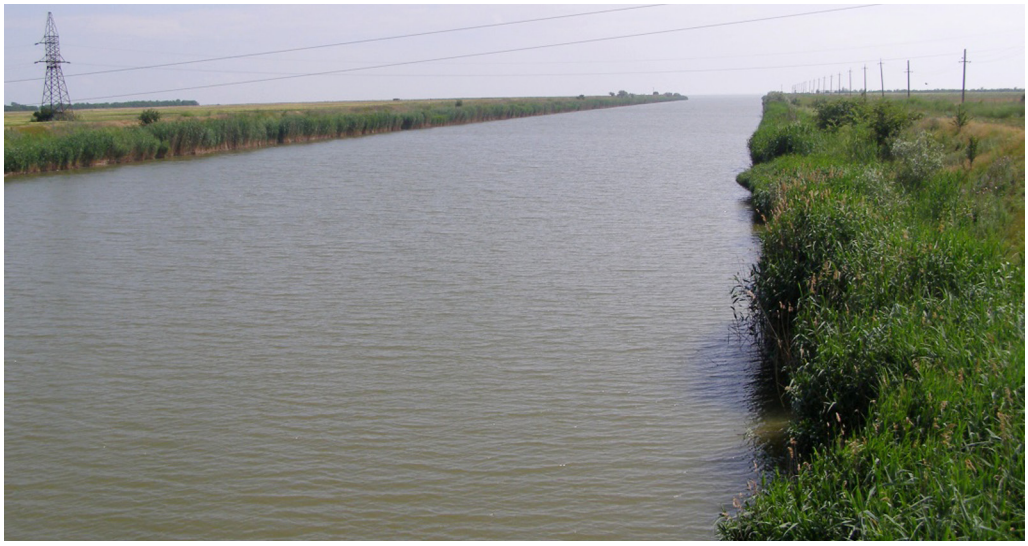

Fig. 4. The Danube–Sasyk Canal

These are the largest embanked floodplains with a regulated water regime in the delta. As a result, 38,000 hectares of floodplains adjacent to the Stentsivsko-Zhebryansky floodplain were converted mainly into rice fields. In general, the transformed area of the Kiliyan arm of the Danube Delta occupies more than 10 thousand hectares. Over the past 25–30 years, due to the management of the sluice system in the Stentsivsko-Zhebryansky floodplains, the water level has been artificially maintained and gradually increased. Long-term maintenance of an elevated water level (up to 40 cm) leads to an

excessive accumulation of organic substances and their slow destruction. Before water regime regulation in this section was established, its vegetation had been represented by all types of organizations, characteristic of the delta areas. But halophytic coenoses occupied the biggest territories due to the close location of the Black Sea. The wealth of animal life, in particular bird fauna, was noted for this plain. After damming and establishing of water regime regulation, trees, shrubs, meadows, and saline vegetation almost completely degraded. The formation of monodominant thickets of *Phragmites australis* with a small proportion of *Typha angustifolia* and *Schoenoplectus lacustris* took place. At the same time, the open water surface is constantly shrinking due to overgrowth and the system loses its mosaic character. Anthropogenic eutrophication of water bodies is currently one of the leading factors of local catastrophic changes in the area.

Since 2008, restoration work has been carried out to deepen the main channels of the Stentsivsko-Zhebryansky floodplain – Murza, Laptysh and Chatal, with a total length of over 34 km. The restoration of the flow had a positive effect on floodplain ecosystems, flora and vegetation, ichthyofauna and birdlife. We classify these changes as post-catastrophic.

The construction of fish ponds and rice fields in the floodplain is the second largest factor causing catastrophic changes of vegetation. Satellite determination of land cover changes showed that the area of hydromorphic landscape complexes (terrestrial, wetland, and hydrophytic ecosystems) increased by 3,282 hectares during the period of 1975–2020. This is a result of agricultural activities in the delta, the overgrowth of lakes and channels, the natural expansion of the delta into the Black Sea, erosion processes, flooding of some areas, etc. (Starodubtsev & Ladyka, 2021). Along the functioning ponds, rice fields, and irrigation channels, only wetland vegetation is observed. The abundance of submerged vegetation in ponds depends on the intensity of their use (Dziuba, 1996). On the territory of non-functioning, former artificial reservoirs, vegetation succession develops in the direction of the meadow and saline-meadow vegetation formation (with the participation of *Tripolium vulgare*, *Puccinellia gigantea*, etc.). Dams are overgrown mainly with weed or steppe vegetation formed by species of a wide ecological range. The elevated parts of dams in the absence of flooding are subject to salinization processes.

In the 1960s, the ecosystem of Yermakov Island was greatly disturbed due to the construction of dams. It was planned to transform the island for the cultivation of *Phragmites australis* with a purpose of paper production on an industrial scale at the Izmail Paper Mill (Odesa region). Over 40 years, as a result of epeirogenetic processes, the surface level of the island dropped by 0.5–0.7 m from the level on the islands that did not undergo damming. In 2010, as part of the World Wildlife Fund project “Restoration of Yermakov Island”, parts of these dams were eliminated. Holes were made in the dam (20–26 m wide) on the northwestern and southeastern parts of the island. The changes in the hydrological regime that occurred as a result of the redamming of Yermakov Island in 2010 (with a total area of 2,300 hectares) caused a catastrophic changes of vegetation cover (**Fig. 5**).

The elimination coincided with an unprecedented rise in the water level in the Danube because of prolonged flooding from December 2009 to July 2010. Only the dams and the most elevated areas remained unflooded on the island. These areas were built in the southwestern part of the island and filled with pulp during the deepening of the Danube Canal during the construction of the Danube–Black Sea dam. The main areas of the island now consist of water basins, long-flooded, medium-flooded, and short- flooded areas and small patches of non-flooded areas.

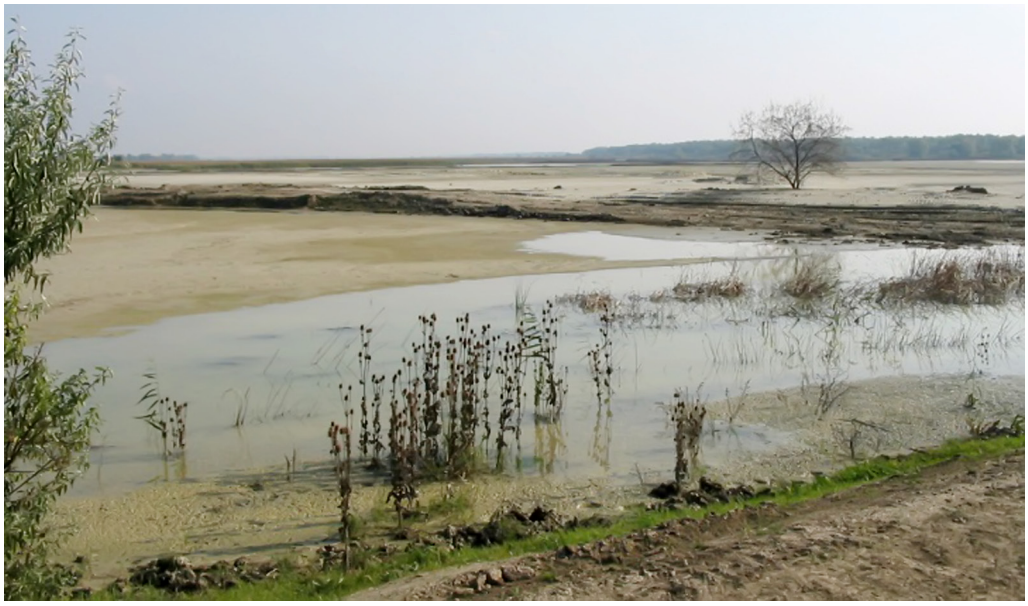

Fig. 5. Formation of the elevated areas in the northeastern part of Yermakov Island

The current differentiation of the plant cover is significantly different from the one that existed before the ecological reconstruction. The tree and shrub vegetation in the low-lying areas, as well as saltmarshes, have completely died out. Areas occupied by meadows decreased. Due to the rise of the water level by 100–150 cm and massive development of *Cladophora species, Phragmites australis and Carex elata* in the summer, the main dominants of marsh communities were a subject to the mass extinction in areas exceeding several hundred hectares. Only aquatic vegetation in the newly formed water reservoirs in the southwestern part of the island, was restored. Submerged plants appeared first and, later, rooted hygrophylous plants. Shallow coastal areas were overgrown with *Typha angustifolia, Schoenoplectus lacustris*, and, later, *Phragmites australis*. With the decrease in waterlogging, their development will not proceed in the direction of the initial marsh community's formation, but the formation of monodominant communities of the abovementioned species in the ratio of 50 %, 30 %, and 20 %. Only 5–7 % will be occupied by *Caricetum elatae* coenoses. Halophytic vegetation with the dominance of *Salicornia perennans* has formed in the higher terrains.

Due to the restoration work conducted in the recent years, the biodiversity of Yermakov Island is now one of the greatest in the Danube Delta. Almost 75 % of plants and about 80 % of animals, characteristic of the Danube Biosphere Reserve, are found there, including more than 50 % of birds in Ukraine. Local shallow lakes have become a location for fish spawning. An expansion of the rare aquatic coenoses listed in the Green Book of Ukraine and formed by *Nymphaea alba*, *Trapa natans* and *Salvinia natans* has been observed. Populations of *Leucojum aestivum*, listed in the Red Data Book of Ukraine (Didukh, 2009a) are spreading in the meadows of the floodplain forest. According to the assessment of the COP15 Biodiversity Summit by the United Nations Environment Program (UNEP) and the UNEP World Environment Monitoring Center, the rewilding of the Danube Delta landscapes was recognized as the flagship of nature restoration

in Europe (Rewilding Danube Delta, 2022). According to the monitoring studies, water exchange on the territory of the island slowed down in recent years due to the formation of alluvial areas in the upper part of the island and their active overgrowth by plants. *Tamarix ramosissima* is the most active species in terms of land reclamation (**Fig. 6**).

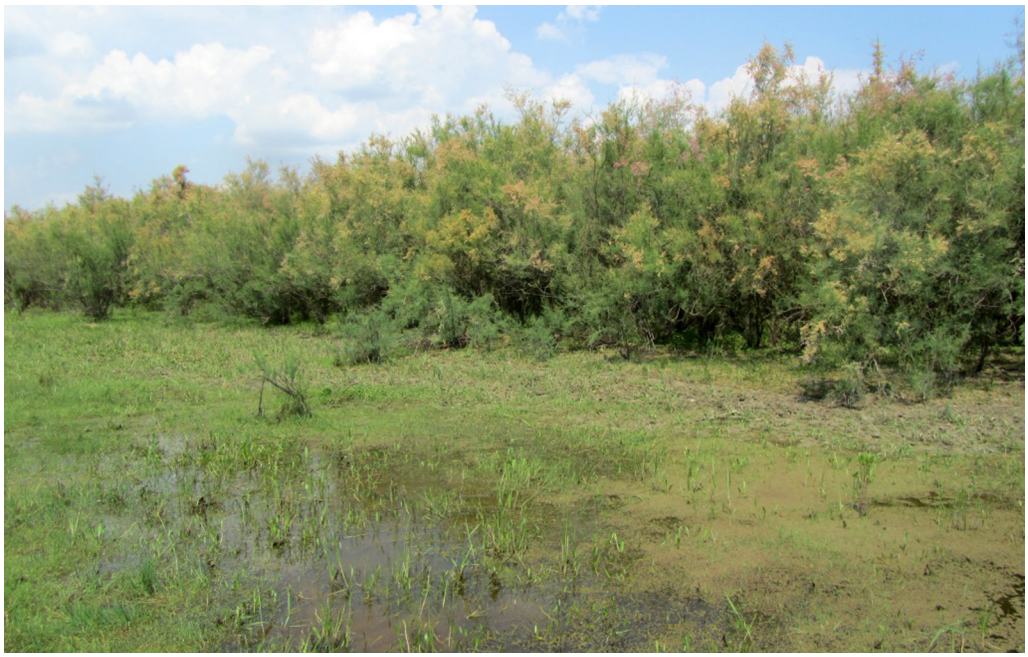

Fig. 6. *Tamaricetum ramosissimae* coenoses on alluvium

Areas overgrown by this species can suppress the water volume entering the island. This creates a negative impact on the functioning of all phytosystems and, accordingly, the animal world. Therefore, the optimal model of the island, from the perspective of the natural phytosystems restoration would be to accelerate the existing water exchange and its supply to all reservoirs throughout the island.

Maly Tataru Island, located in the upper part of the Danube Delta near the city of Izmail, was also reclaimed for agricultural purposes in Soviet times. This island was a typical floodplain geoecosystem in the past. The main part of it was represented by flat, short-flooded territories that were flooded for a short period of time during the spring flood. The riverbed-side ridges in the upper part were not flooded. Meadow vegetation with elements of wetlands and floodplain forests prevailed. After the reconstruction, the natural vegetation was concentrated only on the ridges, in the artificial canals, and in water reservoirs. It was replaced by synanthropic vegetation: segetal in crops and gardens and ruderal – in disturbed areas. On the elevated flat areas, artificial plantations consisting of *Populus canadensis*, *P. nigra*, *Fraxinus excelsior*, *F. pensylvanica*, and *Gleditsia triacanthos* were formed. The island, as a functional part of the floodplain complex of the primary Danubian delta, was lost.

Between 2003 and 2006, parts of the dams were demolished and the access of water from the Danube to the internal lakes of the island during floods was restored. After damming, only the dams and the most elevated flat areas remained unflooded.

They are concentrated along the left bank, specifically, in the area of the livestock farm. The plain area was covered with water because the surface of the island turned out to be 50–70 cm lower than the surface of the other undammed islands. Catastrophic changes in all types of vegetation, except the aquatic ones, occurred. In the shallow reservoirs, during the first years after flooding, syngenetic processes became widespread. A decrease in the flow of the Kiliyan arm of the Danube Delta also had a certain impact. High levels of spring flooding in 2009–2010, as well as in 2017–2018 led to the ecological selection of species that could withstand prolonged flooding.

The tree and shrub communities of the plain areas completely died out. At that time, some species tended to expand due to the overgrowth of newly formed alluvial territories. The most widespread coenoses became those of *Salici-Populetum* and *Salicetum albae*. They include such species as *Amorpha fruticosa, Fraxinus angustifolia*, *F. pensylvanica*, *Morus alba*, *Ulmus laevis*. Territorially, they occupy the peripheral riverside parts of the island, less frequently – the territories of the dams. It should be noted that towards the central part of the island, they become rare and are replaced by coenoses of *Salicetum triandrae*. The latter occupy the largest areas on the island and tend to expand. It is a distinguishing feature of this island, which is a reaction to the change in the island's water regime.

Meadow vegetation is represented by *Alopecuretum arundinacei, Cynodontetum dactyli*, *Brometum tectorum*, *Hordeetum murini*, *Agropyretum repentis* coenoses. The species composition is characterized by the abundance of various ecological groups due to the flood regime. As a result of intensive grazing, the group of synanthropic species is extremely abundant. They are located mainly in the area of the livestock farm and present in such coenoses as *Cannabietum ruderalis*, *Ivaetum xanthiifoliae*, *Arctio lappae-Artemisietum vulgaris*, *Xanthietum californicispinosi*, *Hyoscyamo nigri-Conietum maculati*, *Atriplicetum hastatae*, etc.)

Aquatic vegetation is most represented in the area and occupies all types of reservoirs. The syntaxonomic composition is poorer than on Yermakov Island. The biggest area is covered by coenoses, such as *Nymphaeo albae-Nupharetum luteae*, *Ceratophylletum demersi, Hydrocharitetum morsus-ranae, Lemno-Hydrocharitetum morsus-ranae, Hydrocharito-Stratiotetum aloidis, Salvinio-Hydrocharitetum, Ceratophyllo-Hydrocharitetum,* and *LemnoUtricularietum vulgaris* associations, which are indicators of increasing water eutrophication. Their configuration and distribution are mosaic and depend on water depth. Wetland vegetation, similarly to Yermakov Island, is represented by communities of *Phragmitetum australis, Thelypterido palustris-Phragmitetum australis, Typhetum angustifoliae, Typhetum latifoliae, Iridetum pseudacori, Schoenoplectetum lacustris, Equisetetum fluviatilis, Sparganietum erecti*, and *Glycerietum maximae*. Coenoses of the *Caricion elatae* alliance are also present on the island, but their role is insignificant. Obviously, the formation of wetland communities, which reflect the processes of formation of geomorphostructures of the island, is only at the initial stage. Clearly, with the strengthening of water transit, there will be further overgrowth of water bodies and the formation of swamp and forest-shrub vegetation.

Other islands on the territory of the Ukrainian part of the Danube Delta–Kyslytskyi, Katenka, Mashenka and some smaller islands are not dammed and are used for agricultural purposes. Some of them are abandoned. The development of their vegetation cover shows a trend towards the formation of meadow vegetation transformed due to the absence of spring floods.

Analysis of the European experience of restoration of eutrophicated water bodies (Craft, 2016) shows that the most effective are machine technologies which are well-established in Western Europe (amphibians, swamp harvesters, etc.). However, the cost of such work is very high and currently unattainable for a country at war. In 2008, a herd of Ukrainian gray cattle was settled on Yermakov Island to restore natural grazing. These measures facilitate a gradual restoration of natural wetlands and meadow vegetation. Projects on ecological restoration of delta islands are also carried out in the territory of the Romanian part of the Danube Delta (Marin & Schneider, 1997) and are quite successful.

Pulp backfilling of islands and shallow waters. Vegetation changes caused by backfilling of alluvim with pulp have occured in the Kiliyan arm of the Danube Delta since the 1960s. Now they cover an area of more than 50 hectares. Their appearance was triggered by dredging in the port of Ust-Dunaysk, mainly along the Prorva arm. This work was carried out to maintain the required depth of the shipping channel. In addition to alluvium, riverbed- side ridges and adjacent low-lying flooded areas of the islands were subject to filling by pulp. The height of the artificial ridges reaches 3–4 m. The areas where the pulp storage was completed turned into the highest relief elements in the delta. These newly formed areas are overgrown with species of a wide ecological range. In depressions, *Xanthium strumarium, Carduus acanthoides, Artemisia abrotanum, Suaeda prostrata, Erigeron canadensis, Solidago canadensis, and Cyclachaena xanthifolia* occur. On the ridges *Petasites spurius, Leymus sabulosus*, and *Elytrigia repens* grow. Later, tree and shrub vegetation appeared here, mainly represented by *Tamarix ramosissima, Elaeagnus angustifolia*, and *E. argentea*. Recently, communities of *Hippophae rhamnoides* have formed on these ridges, in some areas, occasionally, with patches of *Ephedra distachia*. The scale of pulp storage on the alluvium of Yermakov Island was much larger.

With the transition of the grain corridor due to the war to the Danube River, dredging operations intensified, and, accordingly, the appearance of new alluvium and changes in vegetation can be expected.

Explosions of military shells. Currently, a new large-scale threat is caused by military actions as a result of the Russian-Ukrainian war. After the explosions, craters are formed in which the original vegetation is completely destroyed and the adjacent vegetation burns out. In the absence of strong wind, burning is local (the coastal part of Poludenny Island), in other conditions (strong wind and the presence of dense vegetation with *Calamagrostio epigei-Hippophaetum rhamnoides* and *Elaeagnetum angustifoliae*) – large-scale (the coastal part of Ankudyny Island).

The restoration of vegetation, including shrub vegetation, in particular *Calamagrostio epigei-Hippophaetum rhamnoides*, is predicted, primarily due to the presence of the *Hippophae rhamnoides* root and shoot system. Restoration of *Elaeagnetum angustifoliae* can be problematic. The unique seaside psamophytic neoendemic complex with the dominance of *Alyssum borseanum*, *Apera maritima*, *Agrostis maeotica*, *Artemisia arenaria*, *Limonium danubiale*, *Elytrigia pontica*, *Melilotus arenarius* etc. undergoes greater transformations due to the invasion of adventive species with wide ecological amplitude. Those and other psammophytic species are extremely vulnerable to disturbances. Changes in the vegetation as a result of explosions in the port areas have a different nature. Overgrowth of the territories will occur according to post-pyrogenic scenarios, and more hydrophilic vegetation will be formed on the craters themselves compared to the original one.

CONCLUSIONS

In recent years, catastrophic large-scale changes have taken place in the Kiliyan arm of the Danube Delta as a result of hydro-technical construction, storage of pulp on alluvium, conversion of large areas of delta into agricultural land, damming and further redamming of islands, quarrying of sand, etc. Anthropogenic changes in vegetation exceed natural ones in terms of scale and transformative impact. These changes have led to the disruption of the ecological regime and the degradation of natural floristic complexes and plant communities in the dynamic zone of the delta. The construction of the Danube–Black Sea Canal blocked the biogenetic channel of the coastal-island part of the Kiliyan arm of the Danube Delta, supporting the exchange of genetic material, primarily representatives of the psammophilous-littoral neoendemic floristic complex between the coastal-littoral regions of the Western and Northern Black Sea coasts. A reduction in the area and diversity of landscapes and degradation of phytodiversity has been noted. It has been established that the preservation, restoration, and maintenance of marsh, psammophyte, and salt-meadow communities in the conditions of regulated river flow and climate change can be achieved through the sustainable management plan. These measures should be preceded by an assessment of negative changes and their trends, as well as strict control over their implementation. The strategy for optimizing the vegetation cover of the Kiliyan arm of the Danube Delta should be directed at maintaining a high level of biological diversity of the Danube Delta, considering the economic interests of local people. This task can be solved only by using traditional types of nature exploitation, land management practices established throughout the historical development of the Danube Delta and with the further restoration of the ecosystems of the Danube floodplain, which were reclaimed in the past. The established features of anthropogenic changes can be used to develop methods for assessing the risk of ecosystems, the intensity of their degradation, and stability for protection, management, and sustainable use of biodiversity, in particular, in the delta regions of the Northern Black Sea area.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, [D.D.]; methodology, [D.D.; T.D.]; investigation, [D.D.; T.D.; L.B.]; data analysis, [D.D.; T.D.]; writing – original draft preparation, [D.D.; T.D.; L.B.]; writing – review and editing, [D.D.; T.D.; L.B.]; visualization, [D.D.; T.D.; L.B.]; supervision, [D.D.]; project administration, [D.D.].

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АНТРОПОГЕННІ КАТАСТРОФІЧНІ ЗМІНИ РОСЛИННОСТІ КІЛІЙСЬКОГО РУКАВА ДЕЛЬТИ ДУНАЮ (УКРАЇНА)

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Вступ. Дельти є унікальними природними екосистемами, які характеризуються високою різноманітністю біотопів. На початку минулого століття природні комплекси дельти Дунаю зазнали значних антропогенних перетворень. Антропогенний, особливо масштабний, тиск на природні екосистеми дельти призвів до катастрофічної зміни екологічного режиму та деградації аборигенних флористичних комплексів і рослинних угруповань. Катастрофічні масштабні зміни відбулися в останні десятиліття внаслідок одамбування як окремих островів, так і заплавних територій і подальшого роздамбування їх унаслідок впровадження проектів відновлення

біорізноманіття, будівництва масштабного глибоководного судноплавного каналу Дунай–Чорне море, перетворення значних площ дельти на сільськогосподарські угіддя, створення штучних водойм, засипки пульпою островів і мілководдя.

Прибережні екосистеми східної частини Кілійського рукава дельти Дунаю також зазнали катастрофічного впливу внаслідок військових дій Росії, головним чином, спричинених вибухами снарядів.

Матеріали та методи. У дослідженні використовували багаторічні порівняльні фітоценотичні спостереження і стаціонарні дослідження. Вивчення антропогенної динаміки рослинності проводили прямими методами – на стаціонарних та напівстаціонарних ділянках. Ми порівняли дані, отримані до будівництва глибоководного судноплавного каналу "Дунай–Чорне море", і останні дані, отримані після його створення. До прямих методів належить метод порівняння поточних даних з історичними картами та геоботанічними описами, представленими в монографії «Державний заповідник "Дунайські плавні"» (Shelyag-Sosonko & Dubyna, 1984).

Результати. У статті висвітлено основні антропогенні зміни рослинності, виявлені на основі багаторічних порівняльних та стаціонарних досліджень. Антропогенні зміни рослинного покриву дельти Дунаю поширені і найбільш яскраво виражені на території Стенцівсько-Жебріянських плавнів, Жебріянської приморської гряди, островів Єрмакова, Машенька, Катенька, Кислицького, Малого і Великого Татару, Великого і Малого Даллерів, у районі Ізмаїльського й Усть-Дунайського портів, у заплавній зоні біля м. Кілія і в більшій частині надзаплавної тераси від м. Вилково до Ізмаїла. Найбільше загроженою є лучна та псамофітна рослинність із представниками псамофітно-літорального неоендемічного флористичного комплексу. Підлягають негативному впливу й заплавні ліси. Лише водні екосистеми більш лабільні до гідрологічних змін.

Висновки. Запропоновано стратегію оптимізації рослинності дельти Дунаю. Встановлені закономірності можуть бути використані для розробки методів оцінки ризику й інтенсивності деградації екосистем з метою охорони, управління та сталого використання біорізноманіття в дельтових районах Північного Причорномор'я.

Ключові слова: антропогенна трансформація, катастрофічні зміни, рослинні угруповання, дельта Дунаю, Україна

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