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Impact of climate change factor on the resource (providing) ecosystem services of the Lower Danube wetlands

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ABSTRACT

Problem Statement. Wetlands perform many vital functions, in particular: accumulation and storage of surface waters; protection from storms and floods; strengthening the coastline and curbing water erosion; hydraulic connection with groundwater; surface water purification; nutrient content; deposit formation; pollutants retention; stabilization of local climatic conditions, especially the amount of precipitation and temperature of the near-surface layer of the atmosphere. They are the world's most productive ecosystems, focus of biodiversity, sources of water and primary productivity on which the existence of innumerable species of plants and animals depends. Wetlands support numerous species of birds, mammals, reptiles, amphibians, fish and invertebrates. The ecological character of wetlands is the totality of their ecosystem components, processes and services at one time or another. Wetland ecosystem services are understood as the benefits that people receive from these. These are providing services (water and food); regulatory services (regulation of floods, droughts, land degradation, etc.); supporting services (soil formation, nutrient cycling, photosynthesis, biodiversity); cultural services (cultural and entertainment, spiritual, religious and other intangible benefits). In Ukraine, there are 2417 wetlands with a total area of about 255 million hectares. Among them are 50 wetlands of international importance with a total area of about 734 thousand hectares, a significant proportion of which falls on the territory of the North-Western Black Sea region coastal zone.

The aim of this study is to determine the state, vulnerabilities and climate change impact on the ecosystem services of the «Chilia Branch» wetlands.

Research Methodology. To determine the periods of drought, the study used the Standardised Precipitation Evapotranspiration Index (SPEI) from April to October 1980-2023. The SPEI index was calculated at a point located in the southern part of the Danube Biosphere Reserve. The assessment of the state of the vegetation cover was carried out on the basis of the analysis of Normalized Difference Vegetation Index (NDVI) the period 2017-2023 at two sites (Ermakov Island and Limba Island). To analyze dynamics land cover in the wetland area, were used Sentinel-2 land use satellite imagery for the period 2017-2021.

Results. Analysis of the SPEI index showed that during the study period there was a positive statistically significant linear trend towards an increase in dry conditions (0.26 / 10 years). In the period 1980-2023 during the growing season on the territory of the "Chilia Branch" wetland, there is a change in weather conditions towards arid, which poses a certain threat. At the same time, it should be noted that the unique hydrological complex of the Danube Delta has a mitigating effect of the atmospheric drought impact on the vegetation. Also, it should be noted that the threat to coastal wetlands is the anthropogenic transformation of coastal natural systems (urbanization processes, expansion of land for agricultural needs, pollution of soil and surface waters), which can lead to loss of habitats of living organisms and deterioration of ecosystem services.

Keywords*: ecosystem services, wetlands, Lower Danube, Danube Biosphere Reserve, NDVI, SPEI, land use, climate change.*

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Introduction. Wetlands, according to Convention on Wetlands [1], «*are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*». According to the UN Environment Program [2], the area of wetlands is about 5.7 million km^2, that is, approximately 6 % of the Earth's land surface, of which 2 % are lakes, 30 % − raised bogs, 26 % − lowland bogs, 20 % − wetlands and 15 % − floodplains. Wetlands perform many vital functions, in particular: accumulation and storage of surface waters; protection from storms and floods; strengthening the coastline and curbing water erosion; hydraulic connection with groundwater; surface water purification; nutrient content; deposit formation; pollutants retention; stabilization of local climatic conditions, especially the amount of precipitation and temperature of the near-surface layer of the atmosphere. They are the world's most productive ecosystems, focus of biodiversity, sources of water and primary productivity on which the existence of innumerable species of plants and animals depends. Wetlands support numerous species of birds, mammals, reptiles, amphibians, fish and invertebrates.

The ecological character of wetlands is the totality of their ecosystem components, processes and services at one time or another. Wetland ecosystem services are understood as the benefits that people receive from these. These are providing services (water and food); regulatory services (regulation of floods, droughts, land degradation, etc.); supporting services (soil formation, nutrient cycling, photosynthesis, biodiversity); cultural services (cultural and entertainment, spiritual, religious and other intangible benefits) [3].

It is known that since 1970, about 35 % of the entire territory of the world's wetlands has been lost. They disappear three times faster than forests, and living organisms that depend on the existence of wetlands, respectively, are in danger of extinction. Therefore, the problem of rational use of wetlands is very relevant, which implies the preservation of their ecological character in the context of sustainable development, which is ensured through the implementation of ecosystem approaches [4].

Pressure indicators on wetlands, according to [5], include: habitat conversion and degradation (land conversion), climate change, pollution and nutrient enrichment, over-exploitation и introductions of invasive alien species.

The concept of "ecosystem services" is absent in Ukrainian legislation, therefore, their inclusion in decision-making is not very common, but the Law of Ukraine "Basic principles (strategy) of the state environmental policy of Ukraine for the period up to 2030" notes the feasibility of "introducing the ecosystem approach into sectoral policy and improving the system of integrated environmental management".

In Ukraine, there are 2417 wetlands with a total area of about 255 million hectares. Among them are 50 wetlands of international importance with a total area of about 734 thousand hectares, a significant proportion of which falls on the territory of the North-Western Black Sea region coastal zone, namely: Lake Kuhurlui, Lake Kartal, Chilia Branch, Maly Sasyk Liman, Shagany- Alibey-Burnas Limans group, Dniester-Turunchuk Crossrivers Area, the northern part of the Dniester Liman, Tiligulskiy Liman, the Dnieper Delta, Tendra, Yagorlytska, Karkinitska and Dzharylgatsky bays, and Big Chapelsk Depression.

Wetlands act as a regulator of such processes as fresh water accumulation and storage, water filtration, absorption from the atmosphere and accumulation of CO_2. Wetland plants absorb CO_2 in the 50 times more than tropical forests, after which they are covered with silt when the water level rises. They are sources of O_2, which is released during photosynthesis, and maintain a balance between CO_2 and O_2.

In addition, the wetlands of the North-Western Black Sea region coastal zone contribute to the regulation of surface runoff, the groundwater level stabilization, the climatic conditions formation (precipitation, humidity and air temperature in the surface layer of the atmosphere), prevention and containment of erosion processes, biodiversity conservation, contribute to the formation of various plant and animal species. They are a source of water supply, fish and hunting resources, supply of wood materials and reeds, wild plant products and other biological resources; provide habitats for rare and Red Data Book species of animals and plants. Wetlands are barriers to mechanical (retain large particles and suspended solids) and physicochemical (retain heavy metal ions and biogenic elements) pollution of surface water bodies.

One of the reasons for the degradation of the North-Western Black Sea region wetlands is the underestimation of their real economic value, the cost of natural resources and services in general [6].

The aim of this study is to determine the state, vulnerabilities and climate change impact on the ecosystem services of the «Chilia Branch» wetlands.

Vulnerability and impact of climate change on wetlands. Strategies directed to increase food production and reduce poverty often involve converting wetlands to agricultural grounds and significantly increasing fertilizer use to increase crop yields. This approach leads to a reduction in the habitat area of local species (and, accordingly, the number of services provided by natural habitats), an increase in the amount of pollutants entering the aquatic environment, the destruction of natural water filters, the loss of ecosystem services provided by wetlands, on which the lives of the poorest segments of the population depend in the first place. Such approaches make it difficult to achieve the goal of improving water quality and sanitary and hygienic conditions, and may even lead to increased poverty among certain population groups [3].

All over the world, the construction of dams, other hydraulic structures and the abstraction of water for agricultural, industrial and domestic needs have led to a change in hydrological regimes and the transport of sediments and nutrients, as well as modification of habitats, disruption of the migration routes of aquatic biota, in particular such as salmon fish. The amount of water stored behind dam walls has increased by 4 times since 1960, and now the volume of water stored in artificial reservoirs is 3-6 times the amount of water in natural rivers [3].

The greatest threat to coastal wetlands comes from the transformation of coastal ecosystems for development, leading to large losses of habitats and services. Other direct factors affecting coastal wetlands are freshwater abstraction, nitrogen loading, overharvesting of biological products, siltation, changes in water temperature and alien species invasions. The main indirect drivers of change are considered to be population growth in coastal areas, coupled with increased economic activity.

Many coastal wetlands are changing as a result of sea level rise, increased intensity and repeatability of storms and tidal waves, leading to changes in hydrological regimes and sediment transport. Such changes have adverse impacts on wetland vegetation and animals, especially species that cannot move to more suitable habitats, as well as migratory species that use wetlands during their life cycle. Destruction and fragmentation of coastal wetlands serving as migration routes has endangered some species and led to the loss of others.

Despite the lack of information about the climate change impacts on specific wetland types and river basins, it is generally considered that removing current pressures on wetlands and increasing their resilience is the most effective way to combat the adverse effects of climate change. Sea level rise, changes in the hydrological regime (especially temperature) of water basins can reduce the amount of resources and services provided by wetlands. In addition, climate change management efforts may also have or exacerbate negative impacts on freshwater and coastal ecosystems. There is an urgent need for information about the climate change impacts on specific types of wetlands and river basins, which could help water and wetland managers, take into account climate change in the planning and management process. Conservation, maintenance or restoration of wetland ecosystems can be an important element of the overall climate change mitigation strategy.

It is predicted, that global climate change will accelerate the loss and degradation of many wetlands and their species, and harm the communities that depend on their services; however, there are no plausible projections yet of the extent of such loss, degradation and damage in the future [3]. At the same time, it is expected that climate change will increase rainfall over more than half of the land surface, and this will provide more water for society and ecosystems. However, the increase in precipitation will not be ubiquitous, and climate change will also be accompanied by significant their reductions in other areas.

Climate changes in the Danube Delta region. The climate of the North-Western Black Sea region belongs to the steppe atlantic-continental climate, and it is more continental and arid compared to other areas of Ukraine. High air temperatures are noted in the summer, the average monthly temperature in July is 31-30 °C, and the maximum varies between 38-41 °C. The annual amount of precipitation is about 250-300 mm [7]. Droughts are often observed here, which can continue throughout the entire spring-summer period (for example, in 2007, 2009, 2012), and also reach the character of severe and extreme droughts [8, 9].

According to observations at the posts and stations network of the Danube Hydrometeorological Observatory of the State Emergency Service of Ukraine in the Ukrainian part of the Danube mouth, there is a trend towards climate warming. The average annual air temperature over the past century has increased by 1.0-1.5 °C, and the maximum annual temperatures have increased by 2-3 °C [10]. There is a increase in water temperature in the reservoirs and streams of the Danube Delta, which is significantly ahead of the increase in air temperature. Significant heating of the earth's surface determines the development of more powerful convective processes. Already, the number of severe weather phenomena associated with convective activity has become more frequent in the region.

The distribution of atmospheric precipitation in the Ukrainian part of the Danube mouth in summer due to active convection is irregularly in time and across the territory. Changes in precipitation patterns lead to increased local runoff and floods [11, 12]. These trends indicate the possibility of an increase in the maximum river discharge entering the estuarine zone and an increase in water temperature, especially in the summer months.

The most vulnerable to climate change is the Ukrainian part of the Danube Delta, where, in addition to external factors of influence, the negative consequences are exacerbated by the processes of redistribution of water flow from the Chilia system of watercourses to the Tulcea channel [13]. Due to the decrease in maximum water levels along the Chilia branch, the deterioration of water exchange between the river and the Danube lakes is expected, as well as a decrease in the flow of small watercourses.

Also, it is possible to add that the average annual air temperature trends in Romania in 1961-2018 show a statistically significant positive trend of 0.27-0.40 °C/10 years. The greatest increase in the average seasonal temperature is observed in the summer and is 0.39-0.52 °C/10 years [14]. In general, in Romania, the amount of precipitation (in 1961-2013) is maintained, with slight tendencies to increase in autumn and decrease in other seasons at some stations [15]. In the Danube Delta, there is a decrease in precipitation to 200 mm per year/10 years [16].

Materials and research methods

Description of the «Chilia Branch» wetlands. «Chilia Branch» wetlands are located in the steppe zone of the North-Western Black Sea region near the state border with Romania, at a distance of 20-30 km southeast of the Kiliya town. The wetlands are part of the Danube Delta. The largest settlement in the vicinity of the site is the Vylkove town (Fig. 1), and the nearest Ramsar wetlands are Lake Sasyk and the Romanian part of the Danube Delta. Other hydrologically related wetlands are the Black Sea and wetlands of the lower Danube Delta. The minimum elevation of the wetlands location is 0.2 m, and the maximum is 0.6 m. The total area of the wetlands is 328 km^2 [17].

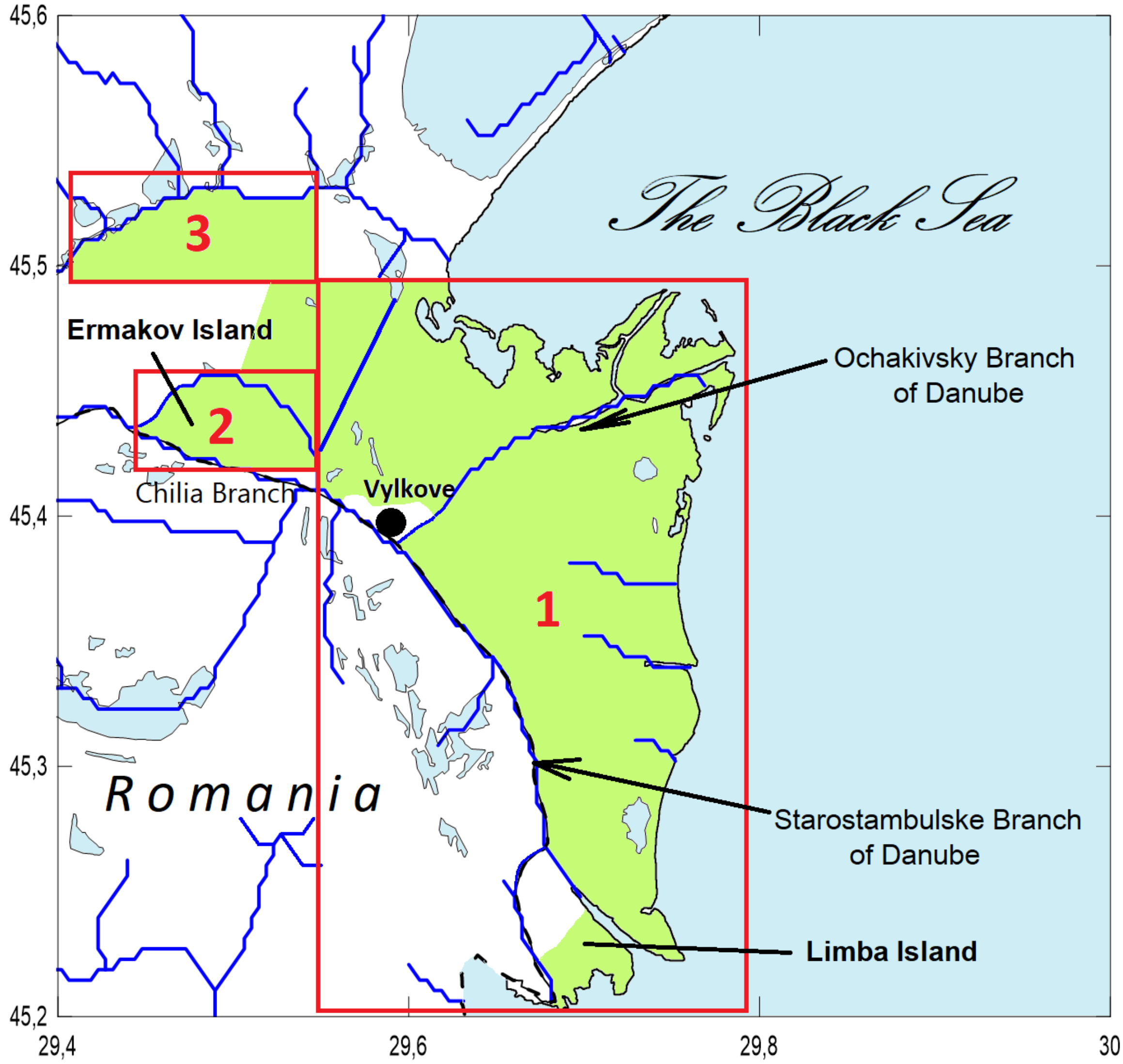


Fig. 1. Map of the "Chilia Branch" wetlands (the study areas – Site 1, Site 2, Site 3 are marked with rectangles, the Danube Biosphere Reserve highlighted in green)

The Danube Delta is an ecotone zone of the river-sea type and is characterized by an extremely high level of species and biotope diversity. Diversity of aquatic biotopes, favorable climate, high productivity of reservoirs, good protective conditions and proximity to grain fields determine the high biological capacity of the delta and its attractiveness for water birds. This is a well-known nesting, molting, wintering and stopping place for water birds during migrations, a large spawning ground for fish and amphibians. This place is home to feeding biotopes of many seabirds.

The main branches and channels of the delta are characterized by very strong currents. The islands are flooded during periods of high water, and the reservoirs located on them are filled. All delta reservoirs are fresh, with the exception of shallow bays in its coastal part. The course of sedimentation processes depends from weather conditions in the Danube basin. As a result of significant erosion and the influence of precipitation from channels and the sea, the wetlands are characterized by significant mobility. The water level in the delta depends on such a seasonal phenomenon as the March floods. The high water level is observed at the end of March and lasts 2-3 weeks. Currently, almost 95 % of the territory of the delta is flooded with water. Between floods, the average water level is 80-180 cm. Surface runoff in July-

August decreases, and in September-October reaches a stable equilibrium. The water level, especially in the reservoirs of the eastern coastal part of the wetlands, depends from the direction and wind speed, and can vary by 90 cm during the day. Danube water is characterized by medium mineralization, and the oxygen content is within normal saturation, although there are periods of its deficiency (winter) or excess (summer). The hydrochemical regime of reservoirs located within the wetlands is unstable. The temperature and salinity of the water, especially in the coastal part of the wetlands, show significant fluctuations, which largely dependent from the action of easterly wind. So, at the river mouth, the water salinity reaches 1.8 ‰ [18].

The wetlands are the delta of the Chilia channel of the Danube. Within their boundaries are swampy areas, floodplain forests, straits, channels, alluvial islands, freshwater lakes, sandy ridges, and in the coastal part − low sandy bars separating the bays from the sea. There are also mainland islands, most of which are located between the Ochakivsky and Starostambulske Branches. The wetlands also include a strip of the Black Sea coast, which is 1 km wide and surrounds the delta in the east. Flat islands of alluvial origin are separated from each other by channels of various sizes. In the lower coastal part, the channels flow into a system of open shallow bays, which are separated from the sea by low silt-sand spits and underwater bars.

The hydrological value of the wetland lies in the fact that the water from the river is used for irrigation of rice fields and the needs of fish farms, as well as for the municipal water supply of the Vylkove and Kilia towns. The main channel is the basic shipping route connecting the port of Ust-Dunaysk with other ports of Ukraine and other countries with access to the Danube.

By type, wetlands refer to estuaries (permanent waters of estuaries and deltas), permanent inland deltas, as well as channels and drainage ditches.

The vegetation of the delta is extremely diverse, with a predominance of hydrophilic plant associations. The cenoses of swamps, open sections of the river, flooded lowland forests, floodplain meadows, as well as halophyte groups include 651 species of vascular plants. The islands of the Chilia mouth are covered with lacustrine and marsh vegetation, mainly with common reeds and cattails. The vegetation of water bodies is represented by many submerged and floating species. In spring and summer, shallow bays and shallow water on flooded islands warm up well and are characterized by high productivity. There are all conditions for the development of plankton, nekton and benthos (primarily crustaceans, mollusks and insect larvae), which provides a rich food base for vertebrates. The flora of the Danube Delta includes 65 endemics of the Ponto-Caspian floristic complex. Sixteen species are listed in the Red Book of Ukraine [19].

An example of the structure of the natural vegetation of a wetland is the distribution by economic plant types of the Danube Biosphere Reserve (DBR) vegetation [20, 21]. Thus, the group of food plants of the DBR (Danube Delta) includes 314 species (33.00 % of the total flora), fodder crops − 281 species (29.58 %), medicinal − 232 species (24.42 %), technical − 178 species (18.74 %), poisonous − 133 species (13.75 %), non-food economic − 77 species (7.00 %) [22].

Wetlands are an important habitat for valuable species of birds, mammals, amphibians, reptiles. The total number of water birds breeding within the wetland is 25 thousand pairs, which nest mainly in reeds, floodplain forests, on small islands and peninsulas. In autumn and spring, up to 133 species of migratory birds can be found here. The migration route is mainly along the coast with resting places on bays and sandbars. The total number of migrants flying through this area every year is about 2-3 million birds. About 28 thousand birds can stay here for the winter. Species of birds from the Red Book of Ukraine that nest here are pygmy cormorant *Phalacrocorax pygmaeus*, curly pelican *Pelecanus crispus*, yellow heron *Ardeola ralloides*, white-eyed pochard *Aythya nyroca*, kentish plover *Charadrius alexandrinus*, eurasian oystercatcher *Haematopus ostralegus* [18].

The waters of the wetlands are the habitat of many species of reptiles, amphibians and fish, as well as spineless. The composition of the ichthyofauna includes mainly local, including anadromous, fish species. Shallow areas of well-heated bays are a place for spawning and growth of fry of many cyprinids and Danube herring. Among the fish listed in the Red Book of Ukraine, there are: Danube salmon *Hucho hucho ssp. hucho* (endemic subspecies), sterlet *Acipenser ruthenus*, striped ruffe *Gymnocephalus schraetser*, Black Sea beluga *Huso huso ponticus*, European mudminnow *Umbra krameri*, Danube streber *Zingel streber streber* and zingel *Z. zingel*. Species of spineless from the Red Book of Ukraine: dragonflies *Coenagrion lindeni* and *C. mercuriale*, molluscs *Turricaspia lincta* [19].

Wetlands are an important recreational center and are of great importance for environmental education and research. Fishing is a traditional activity of the local residents.

Factors negatively affecting on the ecological character of the wetland include: pollution, mass grazing, land cultivation, uncontrolled burning of reeds and illegal fishing and hunting [17].

The Danube Biosphere Reserve (Ramsar Site 3UA003) is located on the territory of the wetland, established in 1998 on the basis of the Danube Plavni Reserve by expanding its territory, in 1999 the Danube Delta International Romanian-Ukrainian Biosphere Reserve was created.

Ermakov Island − is one of the largest islands in the Ukrainian Danube Delta − is 9.6 km long and 3.6 km wide, with an area of about 23 km^2. After 2009, on Ermakov Island, work began on its restoration after partial removal of dams. In the dams surrounding the island along the perimeter, holes were made in several places. This made it possible for the Danube water to enter on the island during the seasonal flood. According to the project, the demolition of part of the dams surrounding the island should lead to the restoration of natural processes on Ermakov − seasonal flooding of the island. In its natural state, every spring Ermakov received the flood waters of the Danube, which enriched the land with nutrients and irrigated the vegetation of the island. During the high water season, spawning grounds and feeding grounds for fish fry were formed on the island. Meadows temporarily turned into lakes, where rare species of water birds lived. During the summer, the water partially left the island, leaving lush vegetation and fertile soils, and the next spring everything was repeated, creating conditions for the development of one of the most biodiverse corners of the Danube Delta [17].

Currently, the flora of the Ermakov Island has 717 species of plants, which is 74.15 % of the flora of the Danube Biosphere Reserve. As for the current state of the island, now the inland lakes on the island are no more than a meter deep, they serve as a feeding ground for pelicans, which, according to rough estimates, are home to about 30,000 individuals [23].

Standardized Precipitation Evapotranspiration Index. To determine the periods of drought, the study used the Standardised Precipitation Evapotranspiration Index (SPEI), which is based on using the monthly (or weekly) difference between the amount of precipitation and potential evapotranspiration, and is a measure of excess or deficit of moisture for the analyzed month [24, 25]. Potential evapotranspiration is the total loss of water as a result of the plant's transpiration process due to its vascular system and water evaporation from the Earth surface. The SPEI index is sensitive to changes in evaporation (caused by temperature fluctuations), is easy to calculate, and allows choosing a time scale.

The presence of a drought is defined as a period in which the SPEI index has a negative value and reaches a value of -1.0 or less (Tab. 1). The beginning of a drought is determined when the SPEI acquires a negative value, the end of a drought is marked by the first positive value of the index after the negative ones.

Table 1

SPEI criteria [8]

SPEI value	Category
≥ 2,00	Extremely Wet
1,50 – 1,99	Very Wet
1,00 – 1,49	Moderate Wet
0,00 – 0,99	Normal
-0,99 – 0,00	Mild Drought
-1,49 – -1,00	Moderate Drought
-1,99 – -1,50	Severe Drought
≤ -2,00	Extreme Drought

The study used the database of the SPEI index [26], provided by researchers from the Pyrenean Institute of Ecology S. Begueria, S.M. Vicente-Serrano et al. The SPEI database offers information about droughts on a global scale in real time, with a spatial step of 1 degree and a variable time step from 1 to 48 months. In this study, the index is applied on a time scale of 6 months.

Normalized Difference Vegetation Index. The assessment of the state of the vegetation cover was carried out on the basis of the analysis of Normalized Difference Vegetation Index (NDVI) [27]. The index is calculated on the basis of Sentinel 3A satellite images and averaged over a 10-day period. The platform contains data for the period 2017-2023.

The NDVI index is a simple measure of the amount of photosynthetically active biomass. For NDVI display a standardized discrete (continuous gradient) scale is used in the range of values from +1 to -1 [28, 29]. Index values corresponding to green phytomass are in the range of 0.2-0.8. The state of vegetation can be assessed by the following index values [30]: 0.71-1.00 – dense healthy vegetation, 0.56-0.7 – healthy vegetation, 0.41-0.55 – satisfactory condition, 0.31-0.40 – bad condition, 0.21-0.30 – oppressed condition.

Sentinel-2 land use/land cover satellite imagery. Most studies use different indices and metrics to distinguish wetlands from other land cover. One such indicator is the classification of various land covers based on Sentinel-2A satellite data, which was launchedin 2015 as part of the European program Copernicus (Sentinel). Sentinel-2 offers satellite imagery with a resolution of 10 to 60 m and has better spatial resolution than the last Landsat OLI/TIRS [31].

Product data Sentinel-2 10m land use/land cover time series, provided by the company Esri, was used in this study [32]. The product displays a global land use/land cover map for the period 2017-2021 obtained from ESA Sentinel-2 images with a resolution of 10 m. The Impact Observatory artificial intelligence land classification model generates annual global land use/land cover estimates divided into 9 classes. Each pixel in the image is assigned a specific land cover class [33].

Results of the study

Influence of drought conditions on the vegetation cover of the "Chilia Branch" wetlands. For the analysis of drought events, the period from April to October 1980-2023 was chosen. The SPEI index was calculated at a point located in the southern part of the Danube Biosphere Reserve. Analysis of the SPEI index showed that during the study period there was a positive statistically significant linear trend towards an increase in dry conditions (0.26 / 10 years).

Periods with excessive moisture were 1980 − spring 1981, 1984-1985, 1987-1988, 1991, 1993, 1997, 2004-2005, 2014 − spring 2015, 2017, spring 2018, 2021. Very wet periods were 1980, 1 984, 1988, 1997, 2021. Extremely wet periods were August 1997 and April 2015 (Fig. 2).

Dry periods were summer 1981-1983, 1986, 1989-1990, 1992, 1994-1995, 1998-2003, 2006-2009, 2011-2013, 2015-2016, autumn 2018 − 2020, 2022-2023. Severe drought was observed in 1983, 1990, 1994, 2000, 2007, 2009, 2012, 2015, 2018, 2019. Extreme drought was observed in July-October 2007, August-October 2012, September 2015, April, August-September 2020, August-October 2022.

As an illustration of the response of the vegetation cover of the "Chilia Branch" wetlands, we present the values of the NDVI index for the period from June 2020 to June 2023 at two sites. The first one is located on Ermakov Island. The second site is located on Limba Island (Fig. 3).

As you can see, despite the fact that in the spring-summer periods of 2020 and 2023 in this area, there was a drought in some months that corresponded to the criterion of extreme, and 2021 was characterized by moisture indicators within the normal range, and June 2021 was moderately humid, the value of the NDVI index in these periods has a close value (Fig. 4), which indicates about the special conditions in the area that have a mitigating effect on the impact of atmospheric drought on the vegetation cover.

Land cover classes changes on the territory of the «Chilia Branch» wetlands. Total area allocated for change assessment land use/land cover (Fig. 1) is 758 km^2 and includes areas of wetlands and the Black Sea. As can be seen from Table 2, the greatest variability with the smallest area is characterized class Bare ground (the coefficient of variation C_V ranges from 57.4 % for the area of all plots to 165.2 % for Site 3). The smallest changes are in the area occupied by water (C_V from 1.6 % for Site 1 to 10.3 % for Site 3). For classes Trees and Flooded vegetation value of C_V, in general, in all selected areas, it has close values (from 20.0 to 28.0 %), with some differences in Site 2 (for the class Flooded vegetation C_V = 15.2 %) and Site 3 (for class Trees C_V = 43.3 %), which can be explained by the features of the selected areas.

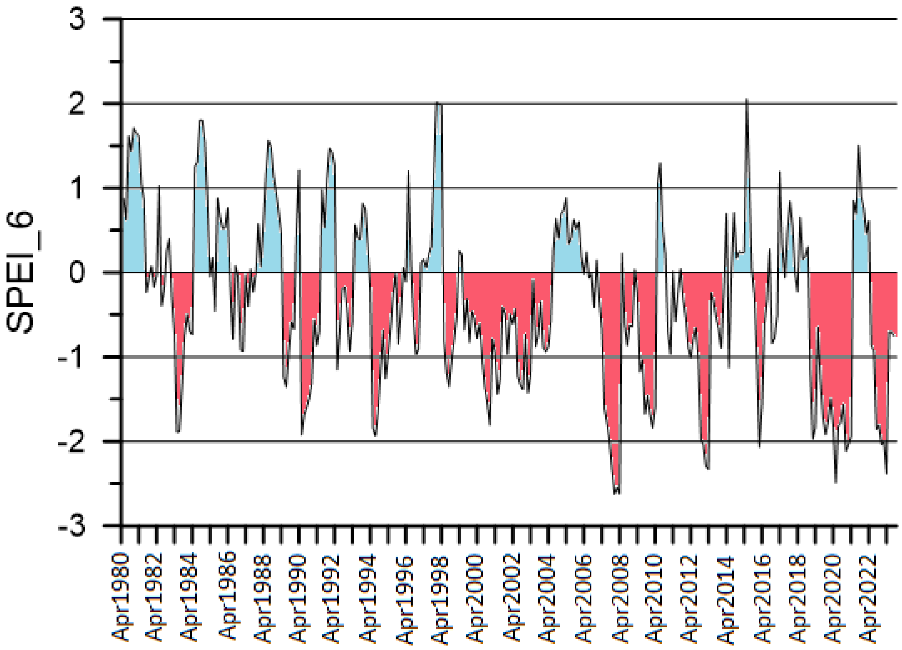
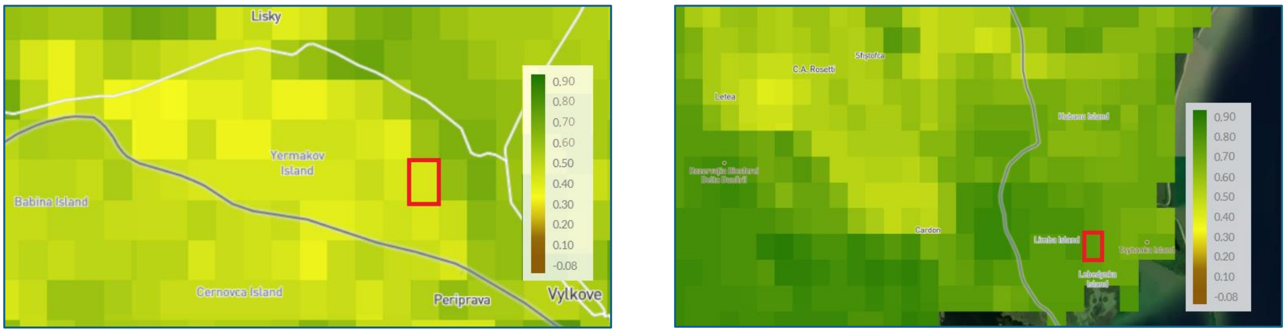


Fig. 2. Interannual course of the SPEI index at a point located in the southern part of the Danube Biosphere Reserve in April-October 1980-2023



(a) (b)

Fig. 3. Sentinel 3A averaged over 10-day NDVI index 01.05.2023: (a) – Ermakov Island, (b) – Limba Island. The red rectangle highlights the pixel for which the time series in Fig. 4

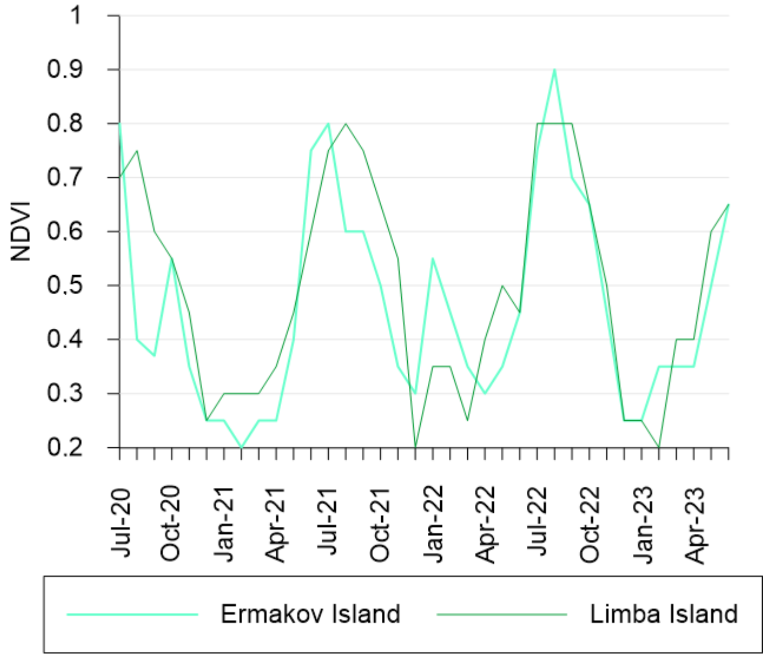


Fig. 4. Sentinel 3A averaged over 10-day NDVI index

Table 2

Mean area ($\bar{S}$), standard deviation (σ), coefficient of variation (C_V) of the area of land cover classes in 2017-2022

Land Cover Class	Site											
	All			Site 1			Site 2			Site 3		
	$\bar{S}$, km²	**σ, km²**	**C_V, %**	**$\bar{S}$, km²**	**σ, km²**	**C_V, %**	**$\bar{S}$, km²**	**σ, km²**	**C_V, %**	**$\bar{S}$, km²**	**σ, km²**	**C_V, %**
1 - Water	159.2	3.0	1.9	144.8	2.4	1.6	7.1	0.1	1.8	7.3	0.8	10.3
2 - Trees	71.2	19.0	26.6	63.5	17.9	28.1	2.4	0.5	22.7	5.3	2.3	43.3
4 - Flooded vegetation	120.0	24.7	20.6	65.9	16.9	25.6	23.1	3.5	15.2	31.0	8.8	28.3
5 - Crops	59.0	3.6	6.2	12.7	2.8	21.7	5.6	1.3	22.9	40.6	0.6	1.4
7 - Built Area	9.9	0.4	4.3	8.6	0.3	3.7	1.3	0.2	12.5	-	-	-
8 - Bare ground	0.7	0.4	57.4	0.6	0.4	73.0	-	-	-	0.1	0.1	165.2
11 - Rangeland	338.2	37.8	11.2	305.5	29.4	9.6	7.9	3.5	43.8	24.8	9.5	38.2

Analysis of interannual changes in the area of land cover classes in 2017-2022 (Fig. 5) showed that 2020 can be distinguished, in which the greatest changes and redistribution of classes of territories were noted. So, in 2020, the area occupied by water is maximum in Sites 1 and 3, the minimum value of the area occupied by trees was noted in all sites, and the area occupied by flooded vegetation and pastures was also redistributed. One of the reasons was the heavy rains that took place in June 2020 in the eastern part of Europe (from 200 to 400 mm of precipitation in two weeks), which subsequently led to an increase in the level in the Lower Danube. In particular, one of the affected areas covered the upper basin of the Prut River (especially in Ukraine, and subsequently in Romania and the Republic of Moldova), where, as a result of intense precipitation, a significant increase in level was observed (up to 3 meters in Romania and Western Ukraine), which caused severe flooding along the Jiu River [34]. Also, the increase in the area occupied by water in 2018 in section 2 can be explained by significant rainfall in June, with which, in particular, the flooding in the central and eastern part of Romania was also associated [34].

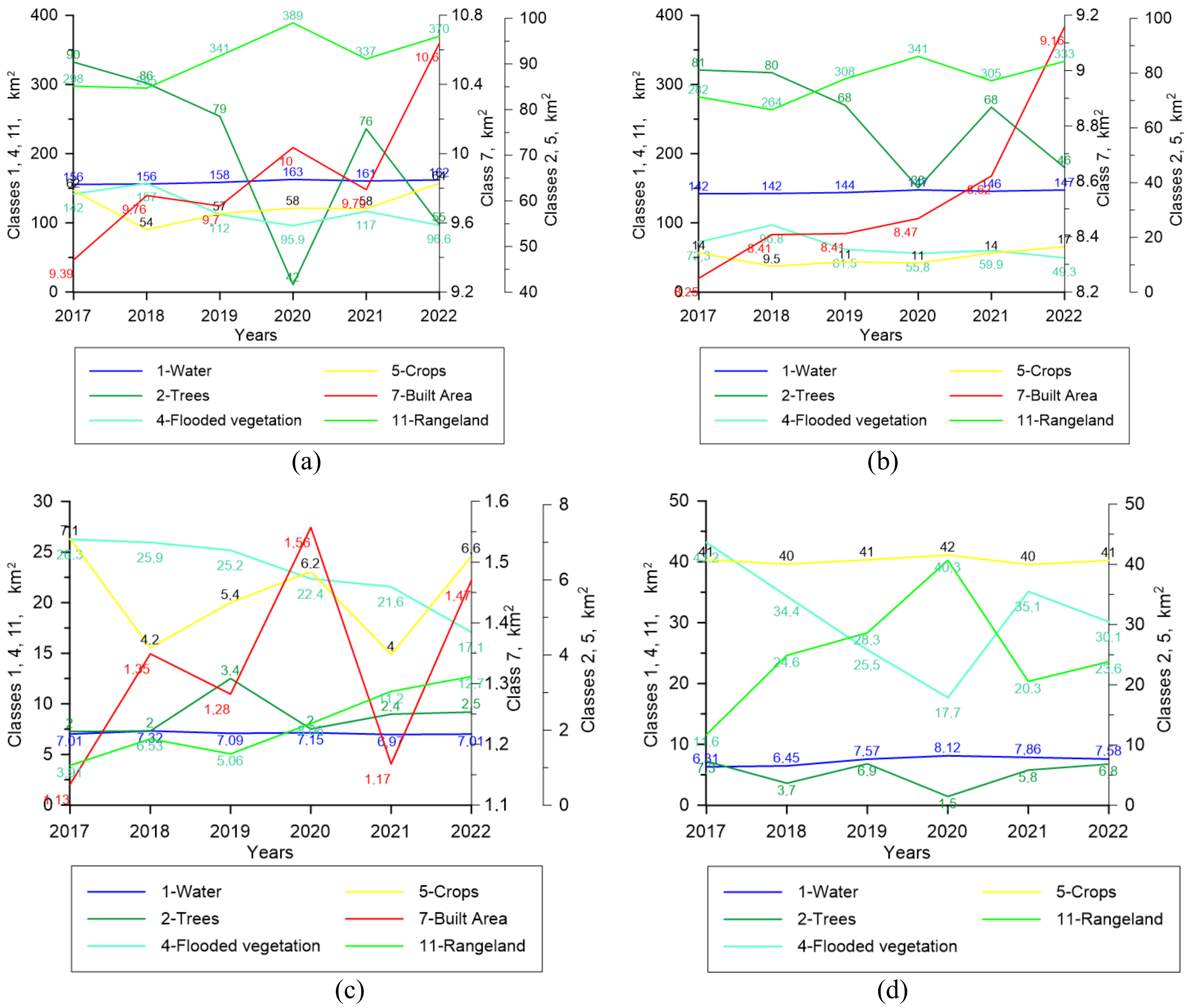


Fig. 5. Area (km^2) of the territory occupied by various land cover classes:
(a) – all sites together, (b) – Site 1, (c) – Site 2, (d) – Site 3

It should be noted that urban development increased from 2017 to 2022, and there is also an increase in the area of agricultural land (due to Site1).

Conclusions. Due to unique physical-geographical, hydrological and climatic conditions, wetlands "Chilia Branch" are the habitat of many valuable species of plants and animals, as well as provide a significant amount of ecosystem services (water and food, regulation of floods, droughts, land degradation, soil formation, nutrient cycling, photosynthesis, biodiversity, cultural, recreational and spiritual).

Climate change is one of the factors that can lead to degradation and loss of wetland ecosystems. In the period 1980-2023 during the growing season on the territory of the "Chilia Branch" wetland, there is a change in weather conditions towards arid, which poses a certain threat. At the same time, it should be noted that the unique hydrological complex of the Danube Delta has a mitigating effect of the atmospheric drought impact on the vegetation.

Having a large catchment area, the Danube bears the load in case of excessive precipitation, which can lead to floods in the Danube Delta, flooding of territories and redistribution of land cover classes and, thus, negatively affect the state of wetland ecosystems.

Also, it should be noted that the threat to coastal wetlands is the anthropogenic transformation of coastal natural systems (urbanization processes, expansion of land for agricultural needs, pollution of soil and surface waters), which can lead to loss of habitats of living organisms and deterioration of ecosystem services.

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Вплив фактору зміни клімату на ресурсні (забезпечуючі) екосистемні послуги водно-болотних угідь Нижнього Дунаю

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Водно-болотні угіддя виконують багато життєво важливих функцій. На водно-болотних угіддях мешкають численні види птахів, ссавців, рептилій, земноводних, риб і безхребетних. Екологічний характер водно-болотних угідь (ВБУ) − це сукупність компонентів екосистеми, процесів і послуг у той чи інший час. Екосистемні послуги ВБУ розуміються як переваги, які люди отримують від них. Це надання послуг (вода та харчування); регуляторні послуги (регулювання повеней, посух, деградації земель тощо); допоміжні послуги (ґрунтоутворення, кругообіг поживних речовин, фотосинтез, біорізноманіття); культурні послуги (культурно-розважальні, духовні, релігійні та інші нематеріальні блага). Метою цього дослідження є визначення стану, вразливості та впливу зміни клімату на екосистемні послуги ВБУ «Кілійске гирло». Для визначення періодів посухи в дослідженні використовувався стандартизований індекс евапотранспірації опадів (SPEI) з квітня по жовтень 1980-2023 років. Індекс SPEI розраховано в точці, розташованій у південній частині Дунайського біосферного заповідника. Оцінку стану рослинного покриву проводили на основі аналізу нормалізованого диференційного вегетаційного індексу (NDVI) за період 2017-2023 рр. на двох ділянках (острів Єрмаков та острів Лімба). Для аналізу динаміки ґрунтового покриву на водно-болотній території були використані супутникові знімки Sentinel-2 за період 2017-2021 рр. Аналіз індексу SPEI показав, що протягом досліджуваного періоду спостерігається позитивна статистично значуща лінійна тенденція до збільшення посушливих умов (0,26 / 10 років). У період 1980-2023 рр. протягом вегетаційного періоду на території ВБУ «Кілійске гирло» спостерігається зміна погодних умов у бік посушливості, що становить певну загрозу. Водночас слід зазначити, що унікальний гідрологічний комплекс дельти Дунаю пом’якшує вплив атмосферної посухи на рослинність. Загрозою для прибережних водно-болотних угідь є антропогенна трансформація прибережних природних систем (процеси урбанізації, розширення земель для сільськогосподарських потреб, забруднення ґрунту та поверхневих вод), що може призвести до втрати місць існування живих організмів та погіршення екосистемних послуг.

Ключові слова: *екосистемні послуги, водно-болотні угіддя, Нижній Дунай, Дунайський біосферний заповідник, NDVI, SPEI, землекористування, зміна клімату.*

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