



## Influence of morphology and functional properties of floodplain water bodies on species diversity of macrophyte communities

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The present study elucidates the morphological and functional characteristics of the water bodies within the Dnipro-Orelskyi Nature Reserve and examines their influence on the species composition of macrophytes. It was determined that the diversity of functional types of water bodies – including confluent lakes, contrafluent lakes, isolated floodplain lakes, canals, and artificial reservoirs – plays a crucial role in determining macrophyte biodiversity and in providing essential ecosystem services. Notably, confluent lakes exhibit the highest levels of species richness, attributable to their pronounced hydrodynamic activity, the variety of microhabitats present, and regular water exchange, which enriches the ecosystem with nutrients. Conversely, isolated floodplain lakes demonstrate the lowest levels of diversity, primarily due to restricted exchange with the river system, eutrophication, and the accumulation of organic matter, which hinder the growth of various plant species. Furthermore, the morphological attributes of water bodies – such as area, depth, shoreline complexity, and axis ratio – significantly influence the species composition of macrophytes. An increase in the size of water bodies correlates with a decline in biodiversity, as competitive species become dominant and the diversity of microhabitats diminishes. Water bodies with an elongated shape and less fragmented shorelines create conditions that are less conducive to macrophyte development, thereby reducing the availability of shallow water zones and sheltered areas suitable for rooting. In contrast, smaller water bodies with irregular shorelines offer a greater variety of habitats, which contributes to the maintenance of high biodiversity levels. The findings of this study contribute significantly to the understanding of the role of water bodies in sustaining ecosystem services and underscore the necessity for sustainable management of natural resources. The research specifically highlights the consequences of alterations in the hydrological regime resulting from reservoir construction. The stabilization of water levels has diminished seasonal dynamics, thereby impacting floodplain ecosystems. The continuous presence of water in the lower regions of the floodplain, along with the absence of regular flooding, has created conditions that markedly deviate from their natural state. The study emphasizes the critical importance of maintaining hydrological dynamics to support ecosystem functions such as water balance regulation, water purification, bank stabilization, and the promotion of biodiversity. Future research should focus on analyzing the effects of seasonal and long-term changes on the structure and functioning of water bodies, evaluating the impacts of anthropogenic and climatic factors, and formulating adaptive water management strategies.

**Keywords:** nature protection; innovative projects; monitoring; bioindication; environmental impact assessment.

### Introduction

The floodplain water bodies of temperate rivers exhibit specific morphological features developed due to the hydrological regime, channel processes and climatic conditions. The natural flow regime and the seasonal components driving it are key to the functions and processes of abiotic and biotic elements (Thayer & Ashmore, 2016). These include morphology, water quality, floodplain, groundwater, riparian vegetation, fish, macroinvertebrates and amphibians. The result is the maintenance of the integrity of floodplain river ecosystems (Hayes et al., 2018). Floodplain water bodies are created within river floodplains and constitute an integral part of riverine landscapes (Fleischmann et al., 2019). Their morphology depends on the type of water body, including old lakes, merged lakes, temporary water bodies, and isolated floodplain lakes (Zhukov et al., 2024). Oxbow lakes are formed due to the alteration of the river channel and the separation of sections of former meanders (Guo et al., 2023). They have a crescent or curved shape, limited by the size of the old channel (Penczak, 2003). The depth of such water bodies is usually shallow, but in the central part, it can reach values typical of deep river sections (Rasmussen & Mossa, 2011). Their banks often have a steep profile on one side and a gentle profile on the other, depending on the flow direction in the past (Boano et al., 2010). Floodplain water bodies play a crucial role in enhancing the productivity of riverine fisheries. The connectivity between these floodplain water bodies and the river channel is a determining factor in the overall fish productivity of the

river system (Penczak, 2003). Merged lakes are created when multiple floodplain water bodies converge to form a singular, expansive system influenced by the contemporary river channel (Obolewski et al., 2018). These water bodies, with irregular shapes and significant surface areas, vary with the river's water levels and feature shoals, bays, and channels. Isolated floodplain lakes form when they become disconnected from the riverbed, usually taking on stable, rounded or oval shapes with low, marshy shores. These shallow lakes are prone to siltation due to limited water exchange with the river (Tan et al., 2019). Temporary floodplain ponds arise during floods when water spills onto the floodplain, resulting in small, irregularly shaped ponds. Their size, depth, and duration depend on the flooding intensity, and they experience rapid morphological changes due to river sediments and evaporation. The morphology of temperate river floodplains is shaped by their origins and the conditions of their formation, influenced by hydrological, geomorphological, and climatic factors (Fagan & Nanson, 2004). Floodplains typically form through sediment deposition, lateral channel migration, and periodic flooding. Their development is closely linked to the dynamic interactions between river flow, sediment load, and the surrounding landscape. Temperate rivers exhibit a seasonal flow regime with significant discharge variations due to snowmelt, rainfall, and other climatic influences. These fluctuations result in regular flooding, shaping the floodplain by depositing fine sediments like silt and clay and coarser materials such as sand and gravel (Weber et al., 2023). Over time, these deposits shape the flat or gently sloping surfaces that define floodplains, highlighting

their importance in the landscape (Tooth et al., 2002). Meandering rivers produce diverse floodplain features, such as oxbow lakes, meander scars, and point bars, through channel migration and cutoff events (Zinger et al., 2011). In contrast, braided rivers, common in areas with high sediment loads and variable flows, create floodplains with numerous interconnected channels and bars, resulting in a fragmented and irregular morphology. Floodplain formation conditions are further affected by tectonic activity, vegetation, and human intervention (Hohensinner et al., 2022). Landscape uplift can create terraces and remnants of former floodplains in tectonically active regions. Vegetation, such as forests and grasslands, stabilises sediments and influences water and sediment distribution during floods. Human activities, such as river regulation, dam construction, and land use changes, can disrupt natural floodplain formation processes, leading to significant morphological alterations (Jakubinský et al., 2021). Overall, the morphology of temperate river floodplains reflects a complex interplay of natural and anthropogenic factors, with their origins and formation conditions influencing spatial patterns, sediment composition, and ecological characteristics (Zhang et al., 2024). Connectivity is an important property of a river-floodplain ecosystem. Reduced connectivity, fragmentation and isolation affect ecological functions and biodiversity. These are some of the most critical threats to floodplain systems. Sediment transport and composition are determined mainly by flow direction and connectivity (Funk et al., 2023).

River-floodplain ecosystems are integral to the provision of numerous ecosystem services that are vital for both environmental health and human well-being (Hornung et al., 2019; Petsch et al., 2023). Among these services, water flow regulation is particularly significant, as floodplains function as natural buffers by absorbing excess water during flood events and subsequently releasing it in a controlled manner. This process mitigates the risk of downstream flooding and contributes to a more stable water supply during periods of drought (Gunnell et al., 2019; Ward et al., 2020). The natural hydrological regulation provided by these ecosystems plays a crucial role in alleviating the impacts of extreme weather events, such as floods and droughts, while simultaneously maintaining the ecological balance of river systems (Sabater et al., 2023). Another essential service provided by river-floodplain ecosystems is sediment and nutrient cycling (Hopkins et al., 2018). Floodplains effectively trap sediments transported by rivers, thereby preventing excessive deposition within river channels and reducing water turbidity. This sedimentation process enriches the soils of floodplains with nutrients, thereby supporting agricultural productivity and enhancing soil fertility (Renshaw et al., 2014). The deposition of organic matter during flood events promotes nutrient cycling, which sustains both terrestrial and aquatic ecosystems within the floodplain (Cierjacks et al., 2011). These ecosystems are also critical for biodiversity conservation, as they provide habitats for a diverse array of plant and animal species (Schindler et al., 2016). The heterogeneous nature of river-floodplain ecosystems encompasses a variety of habitats, including wetlands, riparian forests, oxbow lakes, and temporary ponds (Richards et al., 2018). These habitats serve as breeding, feeding, and migration corridors for numerous organisms, including fish, birds, mammals, and invertebrates (Tawa et al., 2024). The dynamic interactions between aquatic and terrestrial environments foster conditions that support high levels of biological diversity and enhance resilience of ecological functioning (Havrdova et al., 2023; Jayaramaiah et al., 2024). Water purification represents another vital service rendered by river-floodplain ecosystems. These areas filter pollutants, trap sediments, and facilitate the decomposition of organic matter through microbial processes, thereby improving water quality for downstream ecosystems and human consumption (Raniak & Izakovičová, 2024; Jaikawana & Pagdee, 2024). The vegetation found in floodplains plays a crucial role in stabilizing riverbanks, which helps to reduce erosion and prevent the loss of valuable land. Moreover, river-floodplain ecosystems contribute to climate regulation by sequestering carbon in both vegetation and soils (Symmank et al., 2020; Valerko et al., 2024). Wetlands within these ecosystems are particularly effective at capturing and storing carbon, thereby assisting in the mitigation of climate change. Furthermore, these areas provide cultural and recrea-

tional services, offering opportunities for activities such as fishing, birdwatching, and eco-tourism, which support local economies and enhance human well-being (Serra-Llobet et al., 2022). River-floodplain ecosystems deliver critical ecosystem services, including water regulation, sediment and nutrient cycling, biodiversity conservation, water purification, climate regulation, and cultural benefits (Moravčík et al., 2024). The preservation and sustainable management of these ecosystems are essential for maintaining ecological integrity and ensuring the continued provision of these invaluable services to both nature and society (Guo, 2023).

The morphology and functional properties of floodplain water bodies play a crucial role in determining the species diversity of macrophyte communities by influencing the habitat's physical and ecological characteristics (Gyosheva et al., 2020). Variations in these factors affect the suitability of water bodies for various macrophyte species, thereby impacting their distribution, abundance, and overall community structure. Morphological characteristics, including surface area, depth, shoreline length, and volume, significantly influence the availability of space and resources for the growth of macrophytes (Istvánovics et al., 2008). Larger aquatic systems, characterized by extensive surface areas and elongated shorelines, tend to support greater species diversity. This is attributable to varied microhabitats, such as shallow zones, deeper regions, and sheltered bays. These morphological features create various environmental conditions, including variations in light penetration, nutrient availability, and water flow, which facilitate the coexistence of diverse macrophyte species (Happel et al., 2024). The depth and volume of aquatic ecosystems significantly affect the stratification of light and temperature, both of which are essential for the growth of macrophytes. Shallow bodies with stable water levels foster dense and diverse macrophyte communities, as light penetration allows for effective photosynthesis at the substrate level (Shan et al., 2024). Conversely, deeper water bodies may sustain a limited number of species adapted to low-light conditions, decreasing overall biodiversity (Wen et al., 2023). Functional properties, including connectivity to the primary river channel, hydrological regimes, and nutrient dynamics, influence species diversity. Water bodies connected to the main river channel frequently undergo periodic flooding, introducing nutrient-rich sediments and enhancing habitat heterogeneity. These conditions promote the establishment of diverse macrophyte communities by offering a combination of stable and dynamic environments (Weigelhofer et al., 2015). Isolated floodplain lakes or ponds may experience restricted nutrient input and diminished species diversity due to reduced ecological exchange with adjacent water bodies' systems (Jiang et al., 2020). Hydrological regimes, characterized by seasonal variations in water levels, significantly impact macrophytes' growth and reproductive success. Periodic flooding events can establish temporary habitats that facilitate the dispersal of propagules, thereby enhancing species richness (Gerard et al., 2007). Sustained fluctuations in water levels or extreme hydrological disturbances may disrupt macrophyte communities, reducing biodiversity. Furthermore, functional properties, including water quality and trophic status, are essential determinants of macrophyte diversity (Kim & Nishihiro, 2020). Eutrophic water bodies characterized by elevated nutrient concentrations may facilitate the proliferation of a limited number of dominant species, resulting in diminished diversity due to competitive exclusion (Mäemets et al., 2010). Mesotrophic or oligotrophic systems with moderate nutrient levels frequently support more balanced and diverse macrophyte communities (Chmara et al., 2015). The interaction between the morphology and functional characteristics of floodplain water bodies generates diverse habitats that significantly influence the species diversity within macrophyte communities (Marchetti & Scarabotti, 2016). The dynamic nature of these environments, shaped by both physical and ecological factors, underscores the necessity of preserving the integrity of floodplain ecosystems to safeguard their rich biodiversity (Ryfisch et al., 2023).

The aim of the investigation is to examine the influence of morphological and functional characteristics of water bodies on the species composition of aquatic macrophytes in the Dnipro-Orilskyi Nature Reserve for a deeper understanding of ecological processes and ecosystem services they provide.

## Material and methods

The research was conducted during the period of spring and summer of 2024 within the aquatic ecosystems of the Dnipro-Orilskyi Nature Reserve, located in Dnipropetrovska Oblast, Ukraine (Olexander Zhukov et al., 2017). The water bodies within the Reserve are categorized into several systems: the Dnipro riverbed water bodies, the Orilskyi Canal water bodies (an artificial formation), the Mykolaivka ledge system, the Obukhivka ledge system, the Taromske ledge system, the water system of the Protich River, and various artificial reservoirs. A comprehensive database of recorded water bodies in the Reserve comprises 314 distinct objects. Surveys of these water bodies were conducted, during which their depths were measured utilizing a Humminbird HELIX 9 CHIRP MEGA SI+ GPS G4N echo sounder. The area of the studied water bodies was systematically covered with measurement points, the coordinates of which were recorded using a GPS device. The configuration of the water bodies was reconstructed using detailed satellite imagery from the Bing Maps service ([www.bing.com/maps](http://www.bing.com/maps)) and was further refined through field research. The depth map of the Dnipro River channel was developed based on Navionics SonarChart™ data ([www.navionics.com](http://www.navionics.com)). Additionally, data from the Advanced Land Observation Satellite (ALOS) ([www.eorc.jaxa.jp/ALOS/en/index.htm](http://www.eorc.jaxa.jp/ALOS/en/index.htm)) were employed to create a digital elevation model (DEM) with a spatial resolution of 12.5 meters. This DEM was subsequently resampled to a resolution of 1 meter using the kriging procedure (Susetyo, 2016). The digital terrain model was integrated with the digital model of the bottom of the water body to produce a comprehensive digital elevation model encompassing both the above and below water surfaces. The morphometric characteristics of the water bodies were calculated using the lakemorpho package (Hollister & Stachelek, 2017). The direction of water flow serves as a criterion for the functional hydrological classification of floodplain lakes (Dawidek & Ferencz, 2005). Based on the direction of preferential water flow, the water bodies are classified as contrafluent, confluent, contrafluent-confluent, bays, and channels. Intra-lake processes are influenced by hydrophysical factors, hydrochemistry of the floodplain lake catchment, and the hydrobiology of its basin. The quality of lake water is contingent upon the lake's location within the river valley and the availability of river water, which can significantly impact lake eutrophication (Dawidek & Ferencz, 2005).

In May, June, July, and August of 2024, a comprehensive survey of submerged, floating, and emergent vegetation across various water bodies was conducted. The field survey employed the strip transect method (Kolada et al., 2014). This methodology involved the observation of aquatic vegetation along 20-meter-wide strips that were oriented perpendicularly to the shoreline, thereby encompassing the entire vegetation zone from the upper eulittoral region to the outer limits of macrophyte growth. Data collection was performed through wading and boating techniques, utilizing a rake and a bathyscope for effective sampling. At each monitoring site, both the maximum depth of plant cover and the average percentage of plant cover were recorded, and all submerged, floating, and emergent plant species were identified. The resulting community matrix for the hydrobotanical relevés comprised 101 taxa documented across 453 monitoring stations. Plant taxonomy was referenced from the Euro+Med Plantbase (<http://ww2.bgbm.org/EuroPlusMed>).

## Results

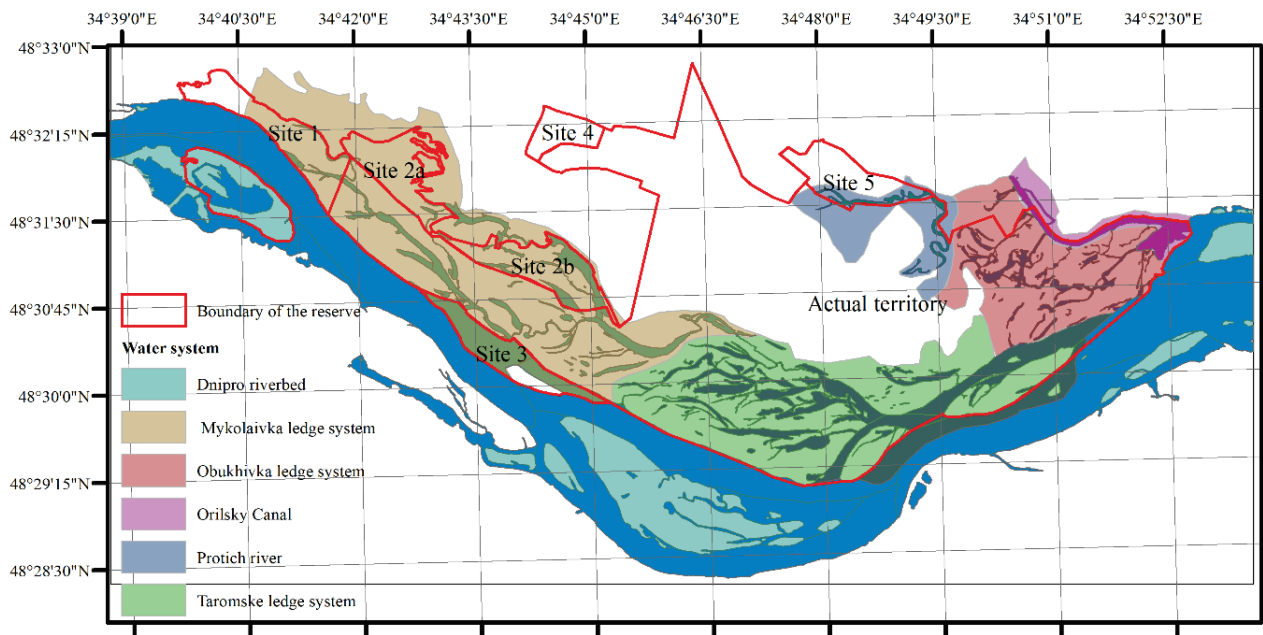
*Water body systems.* The following water systems can be distinguished within the Reserve and its surrounding area: the Dnipro River channel, the Mykolaivka ledge system, the Taromske ledge system, the Óbukhivska ledge system, the Protich River floodplain, and the artificial Orilskyi Canal (Fig. 1). These systems connect the water bodies themselves and the areas of floodplain land close to them. Of course, there are also areas of relief that are less than 78 metres above sea level. Within the designated boundaries of the Reserve, including the territories earmarked for future inclusion, floodplain ecosystems and water bodies encompass an area of 3,007.7 hectares (Table 1).

When considering the projection of the Reserve onto the Dnipro riverbed, the total area covered by floodplain ecosystems and water bodies expands to 5,863.9 hectares. A substantial portion of this area is comprised of the surface of the Dnipro riverbed itself, where the direct water surface constitutes 78.1% of the total area; the remaining surface is characterized by islands and the riverbank. Additionally, the Orilskyi Canal exhibits a significant water coverage, accounting for 44.9% of its surface area. In contrast, for other types of aquatic systems, the land area exceeds that of the water area. Notably, the Dnipro River bed contains a considerable volume of water, representing 89.7% of the total water content. Furthermore, the water bodies located at the Taromskiy and Mykolaivskiy escarpments serve as significant water reserves. It is important to note that the length of the Dnipro riverbed coastline is comparatively less than that of other water systems.

*Functional types of water bodies.* A total of 312 water bodies were identified within the study area. Among these, 93 (29.8%) were classified as Channels, 54 (17.3%) as Contrafluent lakes, 52 (16.7%) as Isolated floodplain lakes, 50 (16.0%) as Bays, 38 (12.2%) as Contrafluent-confluent lakes, 17 (5.5%) as Confluent lakes, and 8 (2.6%) as Artificial reservoirs. The Artificial reservoirs are associated with the Orilsk Canal and the Dnipro River channel (Fig. 2). Contrafluent lakes and Isolated floodplain lakes are the most prevalent in the Taromsk escarpment water system, while Contrafluent-confluent lakes and Confluent lakes are predominantly found in the Obukhiv water system. Bays are frequently observed in the Mykolaiv water system. Channels are the most common water bodies in the Dnipro riverbed, the Orilskyi Canal, and the Protich River. Notably, Channels are primarily located in the Dnipro River channel, the Orilsk Canal, and the Protich River channel.

Functional types of water bodies have their own morphological features (Table 2). Channels and Artificial water bodies had the largest surface area, and Bays, Confluent lakes, and Isolated floodplain lakes had the smallest (Table 2). Confluent lakes and Channels had the most developed shoreline, and Confluent lakes and Isolated floodplain lakes had the least developed shoreline. Artificial water bodies differed significantly in terms of maximum depth from other types of water bodies. Artificial water bodies are characterised by the largest average surface area ( $22.2 \pm 18.4$  ha) and significant volume values, reflecting their engineering design for purposes such as water storage or resource management. In contrast, Confluent lakes are the smallest and shallowest, with limited volumes and surface areas, indicating their local ecological and hydrological role. Channels with the deepest depth ( $8.0 \pm 2.1$  m) and the largest volume ( $1221.6 \pm 634.7 \times 10^3$  m<sup>3</sup>) dominate in terms of hydrological capacity, which underlines their importance for water flow and storage. Natural water bodies, such as Confluent lakes and Isolated floodplain lakes, have a more irregular shoreline, as indicated by slightly higher shoreline development scores, which indicate more complex perimeters that can support diverse ecosystems.

Bays characterized by shallow areas and varying depths are more likely to function as critical ecological habitats rather than as significant hydrological features. The data further elucidates distinctions in the geometric properties of various water bodies. Canals and artificial reservoirs typically exhibit elongated shapes, as indicated by elevated values of their major and minor axes, which enhances their suitability for specific functions, such as flow regulation. In contrast, natural water bodies, including Bays and Isolated floodplain lakes, tend to be more compact in both size and shape, reflecting their formation through natural processes. The data collected demonstrates a diversity of water bodies concerning their morphometric characteristics and functional roles. Canals and artificial water bodies are notable for their substantial size and capacity, underscoring their significance within hydrological and anthropogenic systems. Conversely, smaller natural water bodies, such as tributary lakes and bays, fulfill essential ecological functions. This analysis underscores the interplay between natural and anthropogenic water bodies in facilitating both ecological and hydrological processes.

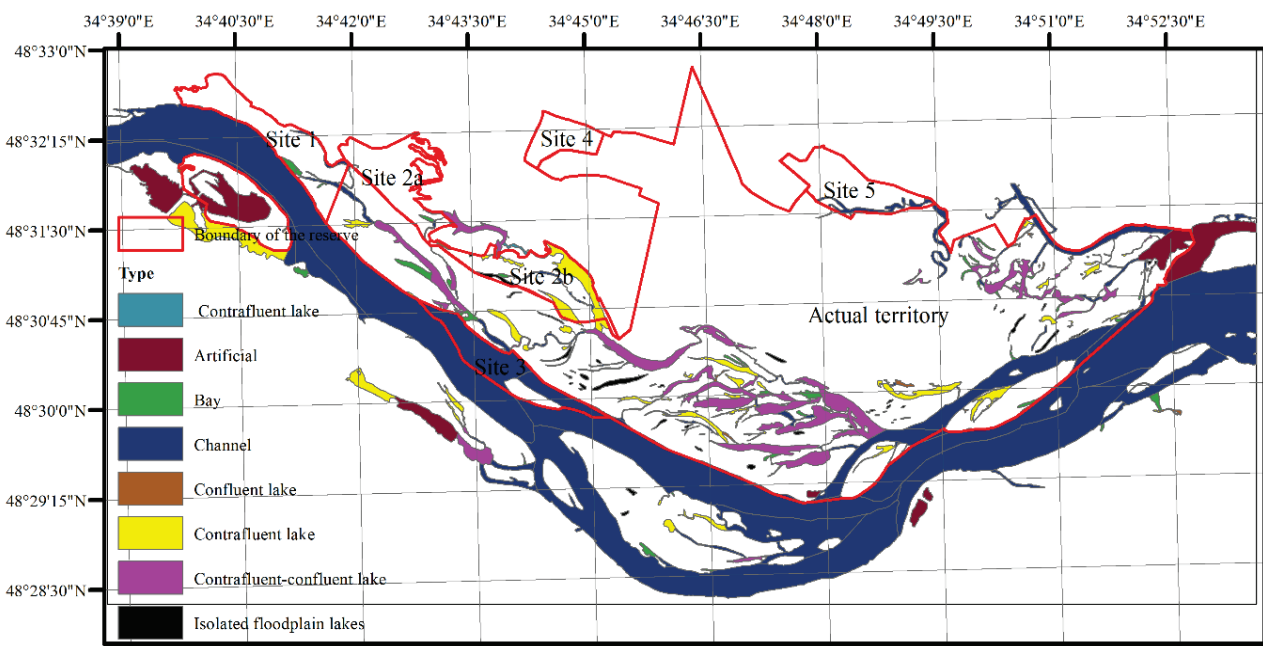


**Fig. 1.** Location of the main water body systems within the Reserve: the red line shows the boundaries of the Reserve (Actual territory) and the locations planned to be included in the Reserve (Site 1, ... 5). Water systems combine aquatic, wetland, meadow and salt marsh ecosystems where groundwater reaches the root layer of the soil and usually has a relief level of less than 78 metres above sea level

**Table 1**  
Structure of water systems in the Dnipro River floodplain in the ‘Dniprovsko-Orilskyi’ Nature Reserve

Water body system	Area within the reserve		Area		Water surface area			Shoreline length		Volume	
	ha	%	ha	%	ha	%*	%**	km	%	10 <sup>3</sup> m <sup>3</sup>	%
Dnipro riverbed	161.2	5.4	2463.2	42.0	1924.5	69.7	78.1	161.4	37.5	116882.7	89.7
Mykolaivka ledge system	1082.7	36.0	1386.4	23.6	273.6	9.9	19.7	84.2	19.6	4124.3	3.2
Obukhivka ledge system	466.8	15.5	533.3	9.1	71.1	2.6	13.3	51.8	12.0	600.4	0.5
Taromske ledge system	1038.1	34.5	1144.1	19.5	415.2	15.0	36.3	109.8	25.5	6816.1	5.2
Orilsky Canal	59.5	2.0	120.8	2.1	54.2	2.0	44.9	11.3	2.6	1669.0	1.3
Protich river	199.4	6.6	216.2	3.7	22.8	0.8	10.5	12.0	2.8	163.8	0.1
Total	3007.7	100.0	5863.9	100.0	2761.3	100.0	47.1	430.5	100.0	130256.3	100.0

Notes: \* is a percentage of the column total, i.e. the share of the water surface of the respective water system in the total area of the water mirror; \*\* is a percentage of the water surface area of the respective water system in its total area (water surface together with land).



**Fig. 2.** Location of functional types of water bodies: the red line shows the boundaries of the Reserve (Actual territory) and the locations planned to be included in the Reserve (Site 1, ... 5)

*Analysis of variation and discriminant capabilities of morphometric features of functional types of water bodies.* The principal component analysis (PCA) conducted on the morphometric features of

water bodies facilitated the extraction of four principal components, each exhibiting eigenvalues greater than one (Table 3). This analysis delineates four principal components (PC1–PC4), each representing

distinct dimensions of morphometric variability. The first principal component (PC1) accounts for the highest proportion of variance and is predominantly influenced by size-related characteristics. Notable positive loadings are recorded for surface area (0.99), volume (0.98), major axis (0.90), shoreline length (0.94), and outcrop (0.88), suggesting that this component primarily encapsulates the overall spatial extent and size of the water bodies. Additional significant contributions are observed from mean depth (0.75) and maximum depth (0.79), further underscoring the importance of size and depth in defining this dimension. The second principal component (PC2) pertains to shape and complexity, with substantial contributions from shoreline development (−0.82) and axis ratio (0.77). The pronounced negative loadings associated with shoreline development imply that water bodies characterized by irregular perimeters are inversely correlated with those exhibiting more elongated and regular shapes, as indicated by the positive loadings from the axis ratio. Consequently, this component effectively differentiates water bodies based on their complexity and elongated morphology.

PC3 accounts for variations associated with both depth and shape. The mean depth (0.46) and maximum depth (0.40) exhibit positive values, whereas the axis ratio (−0.57) presents a significant negative value. This finding indicates that deeper water bodies are generally characterized by a less elongated shape, thereby introducing a depth-related dimension to the observed variability. Conversely, PC4 elucidates more nuanced variability, incorporating factors such as maximum depth (0.26), mean depth (0.24), sampling (−0.29), and axis ratio (0.26). These loadings underscore the complex interplay between depth, wind drift, and shape elongation, although the contri-

**Table 2**

Morphometric features of functional types of water bodies (mean ± standard deviation)

Morphometric feature	Functional types of water bodies						
	Contrafluent lakes	Confluent lakes	Channels	Contrafluent-confluent lakes	Bays	Isolated floodplain lakes	Artificial water bodies
N	54	17	93	38	50	52	8
Surface area, ha	3.1 ± 2.8	0.5 ± 0.5	22.7 ± 70.2	6.1 ± 6.5	0.8 ± 0.7	0.5 ± 0.8	22.2 ± 18.4
Shoreline length, km	1.1 ± 1.2	0.4 ± 0.3	2.4 ± 3.9	1.9 ± 1.4	0.5 ± 0.3	0.4 ± 0.4	2.7 ± 2.1
Shoreline development	0.4 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Max depth, m	2.5 ± 2.4	1.3 ± 0.6	2.3 ± 5.5	4.4 ± 2.5	1.5 ± 1.2	1.1 ± 0.6	13.2 ± 3
Volume, 10 <sup>3</sup> m <sup>3</sup>	63.7 ± 217.1	2.7 ± 3.7	1221.6 ± 634.7	118.3 ± 173.3	6.9 ± 13.5	3.4 ± 7.4	1017.9 ± 832
Mean depth, m	0.8 ± 0.7	0.5 ± 0.2	0.8 ± 1.9	1.4 ± 0.8	0.6 ± 0.4	0.4 ± 0.2	4.9 ± 1.2
Max length, m	349.0 ± 311.1	151.5 ± 90.6	693.6 ± 1225.1	558.4 ± 395	203 ± 123.6	156.1 ± 160.5	824.2 ± 476.2
Max width, m	79.0 ± 74.2	42.7 ± 25.6	146.8 ± 262.8	148.1 ± 80.2	50.2 ± 35.7	34.8 ± 18.0	327 ± 172.5
Mean width, m	52.1 ± 48.9	24.7 ± 13.6	92.0 ± 159.5	87.9 ± 44.9	30.4 ± 20.1	24.8 ± 12.6	221.2 ± 119.8
Major axis, m	527.5 ± 477.1	198.3 ± 123.6	1120.4 ± 1711.5	797.6 ± 575.3	264.4 ± 158.1	192.3 ± 201.6	1006.3 ± 617.8
Minor axis, m	195.7 ± 181.2	93 ± 56.2	416.9 ± 734.1	343.2 ± 223.2	100.1 ± 67.2	71.3 ± 46.6	628.3 ± 372.1
Axis ratio	0.4 ± 0.2	0.5 ± 0.2	0.4 ± 0.2	0.5 ± 0.3	0.4 ± 0.2	0.5 ± 0.3	0.7 ± 0.1
Fetch, m	75.7 ± 90.2	37.9 ± 23.5	137.1 ± 253.5	141.6 ± 87.7	49.9 ± 37.9	35.0 ± 18.8	395.9 ± 211

**Table 3**

Loadings on the morphometric features extracted after principal component analysis and factor structure coefficients extracted after discriminant analysis (only the coefficients that achieved statistical significance at a P-value of less than 0.05 are presented)

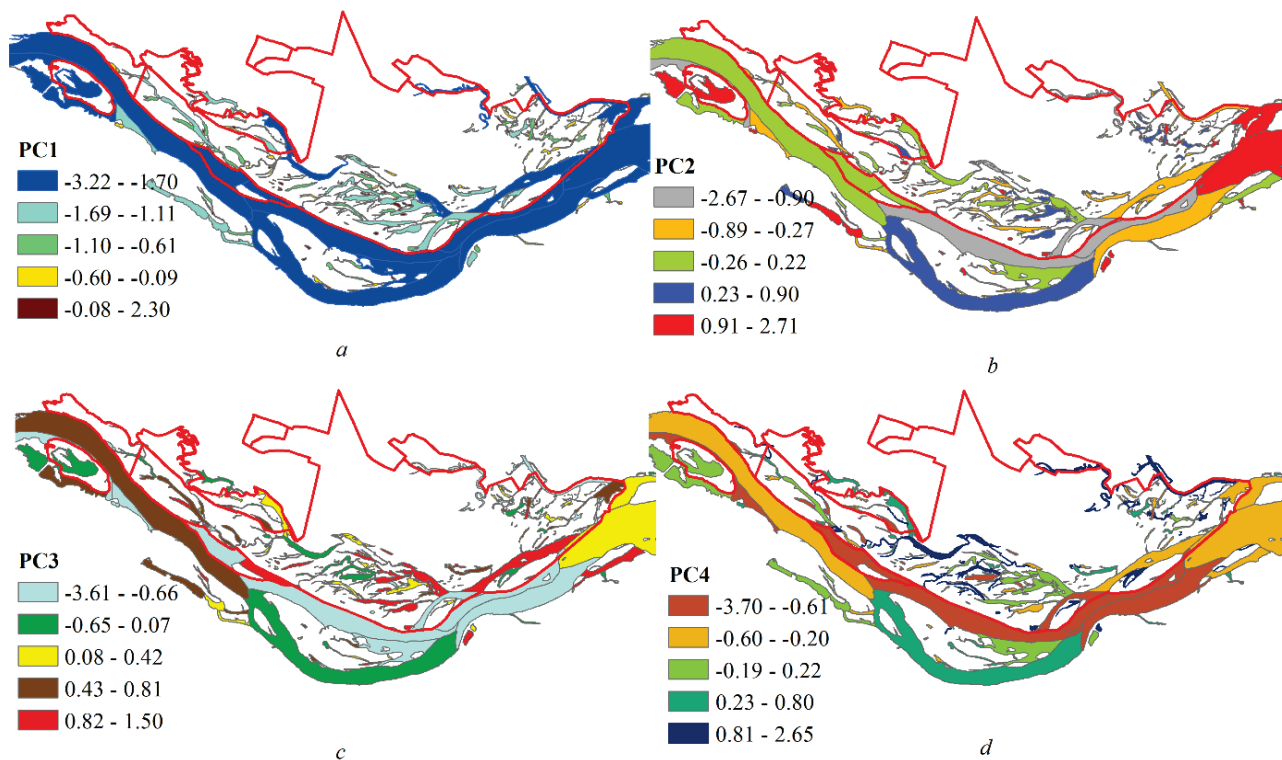
Morphometric feature	Principal component analysis				Discriminant analysis			
	PC1	PC2	PC3	PC4	function 1	function 2	function 3	function 4
Surface area	0.99	–	–	–	0.22	0.70	–	–
Shoreline length	0.94	−0.32	–	–	0.36	0.65	–	–
Shoreline development	0.31	−0.82	–	0.42	0.71	–	0.19	−0.34
Max depth	0.79	–	0.40	0.26	–	0.82	−0.38	–
Volume	0.98	–	–	–	–	0.80	−0.17	–
Mean depth	0.75	0.41	0.46	0.24	−0.14	0.81	−0.39	–
Max length	0.94	−0.26	–	–	0.27	0.59	–	–
Max width	0.93	0.18	−0.21	–	0.13	0.76	–	–
Mean width	0.96	–	–	–	0.14	0.75	–	–
Major axis	0.90	−0.42	–	–	0.40	0.58	–	–
Minor axis	0.95	–	−0.29	–	0.28	0.74	–	–
Axis ratio	–	0.77	−0.57	0.26	−0.22	0.26	–	0.18
Fetch	0.88	0.25	–	−0.29	–	0.71	–	–

The accuracy of the classification for the Confluent lake type was 64.7%, but errors were noticeable in the classification of observations as Isolated floodplain lakes (5 cases) and other classes. Contrafluent-confluent lakes were correctly classified in only 47.4% of cases, with a significant number of errors, including classification as Canal (8 cases) or Contrafluent lake or Isolated floodplain lakes (4 misclassifica-

tion of this component is relatively minor when compared to the first three principal components. Overall, the PCA results suggest that the primary source of variation among water bodies is their size, as reflected in PC1. Shape complexity, which is characterized by shoreline development and axis ratios, emerges as a secondary yet distinct dimension in PC2. Additionally, depth and its interaction with form contribute to further variability in PCs 3 and 4. This analysis illustrates the multidimensional nature of morphometric features, where size, shape, and depth are pivotal in differentiating between various types of water bodies. The findings provide a robust foundation for understanding the functional and ecological diversity of these aquatic systems. The first four principal components exhibited consistent spatial patterns of variability (Fig. 3).

Discriminant analysis indicated that various morphometric features significantly contributed to the discriminant functions. The overall percentage of correct classifications across all categories was 58.7%. The Canal water body type exhibited the highest classification accuracy, with 75.3% of observations correctly assigned to their respective classes (Table 4). The primary misclassifications for this category involved instances where observations were incorrectly classified as Bay (7 misclassifications) and Isolated floodplain lakes (6 misclassifications). Isolated floodplain lakes represented the second most accurate category, achieving a correct classification rate of 71.2%, with the predominant errors occurring in classifications as Bay (7 instances) and Channel (5 instances). The Artificial water body type demonstrated an accuracy of 62.5%, with misclassifications primarily involving Contrafluent-confluent lake (2 instances) and Confluent lake (1 instance).

tions each). The category Bays had a rather low classification accuracy of 42.0%. The most frequent errors were classification as Isolated floodplain lakes (14 cases) and Channel (14 cases). The Contrafluent lake water body type showed the lowest classification accuracy of 38.9%. Errors included classification as Channel (15 misclassifications) and Contrafluent-confluent lake (10 misclassifications).



**Fig. 3.** Spatial variation of the principal component 1–4: principal component 1 (a) describes 71.3% of the variability of features and explains the variation in the size of water bodies; principal component 2 (b) describes 15.8% of the variability of features and explains the variation in the shape of water bodies, which is associated with an increase in elongation with a simultaneous decrease in the major axis of coastal development; principal component 3 (c) describes 6.7% of the variability in the features and explains the variation in the shape of the water bodies associated with an increase in elongation with a simultaneous increase in minor axis and decrease in mean depth, principal component 4(d) describes 3.8% of the variability in the features and explains the variation in the shape of the water bodies associated with an increase in elongation with a simultaneous increase in mean depth, coastal development and decrease in fetch

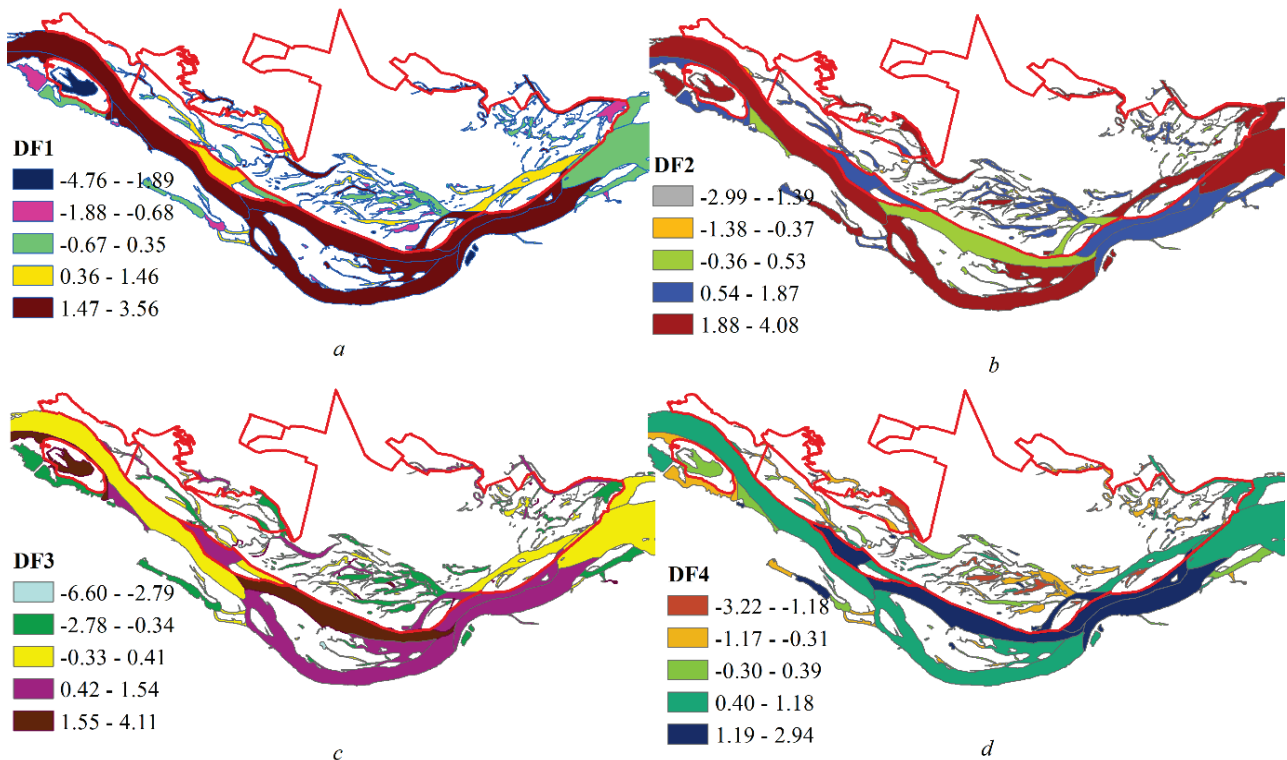
The analysis revealed that surface area exhibited a stronger correlation with Function 2 (0.70) in comparison to Function 1 (0.22), underscoring its greater significance within this context. Similarly, shoreline length made a notable contribution to both Function 1 (0.36) and Function 2 (0.65), with a more pronounced impact observed in the latter. Shoreline development demonstrated the strongest association with Function 1 (0.71), while also contributing to Function 3 (0.19) and Function 4 (−0.34), thereby indicating its relevance across multiple functions. Maximum depth displayed a robust positive correlation with Function 2 (0.82) and a negative correlation with Function 3 (−0.38), which emphasizes its role in differentiating functional types along these dimensions. The volume of the water bodies exhibited a similar trend, significantly contributing to Function 2 (0.80) while being negatively correlated with Function 3 (−0.17). Conversely, the average depth of the ponds revealed negative associations with both Function 2 (−0.14) and Function 3 (−0.39), suggesting a distinct yet less favorable impact. The maximum length and maximum width of the water bodies emerged as influential predictors, with maximum

length contributing to Function 1 (0.27) and Function 2 (0.59), while maximum width demonstrated a stronger correlation with Function 2 (0.76) than with Function 1 (0.13). Additionally, the major and minor axes of the water bodies played a significant role, with both axes exhibiting greater contributions to Function 2 (0.58 and 0.74, respectively) compared to Function 1 (0.40 and 0.28). The axis ratio positively influenced Function 2 (0.26) and Function 4 (0.18), while it was negatively correlated with Function 1 (−0.22). Notably, fetch was uniquely associated with Function 2 (0.71), highlighting its exceptional relevance for this discriminant function. In summary, Function 2 emerged as the most discriminative, demonstrating the strongest relationships with a diverse array of features, including surface area, shoreline length, maximum depth, volume, and fetch. This underscores the significance of these morphometric features in distinguishing between the analyzed functional types of water bodies, while Features 1, 3, and 4 serve a secondary yet complementary role. Discriminant functions 1 through 4 exhibited consistent spatial patterns of variability (Fig. 5).

**Table 4**

Classification matrix based on the results of the discriminant analysis: the rows indicate the observed classes and the columns indicate the predicted classes (the numbers indicate the number of observed classes that were assigned to the corresponding category based on the results of the discriminant analysis)

Observed class	Percent of correct prediction	Predicted class						
		Contrafluent lake	Confluent lake	Channel	Contrafluent-confluent lake	Bays	Isolated floodplain lakes	Artificial water body
Contrafluent lake	38.9	21	–	15	10	6	2	–
Confluent lake	64.7	–	11	–	–	1	5	–
Channel	75.3	4	–	70	5	7	6	1
Contrafluent-confluent lake	47.4	4	–	8	18	3	4	1
Bays	42.0	2	–	9	4	21	14	–
Isolated floodplain lakes	71.2	3	–	5	–	7	37	–
Artificial water body	62.5	–	1	–	2	–	–	5
Total	58.7	34	12	107	39	45	68	7

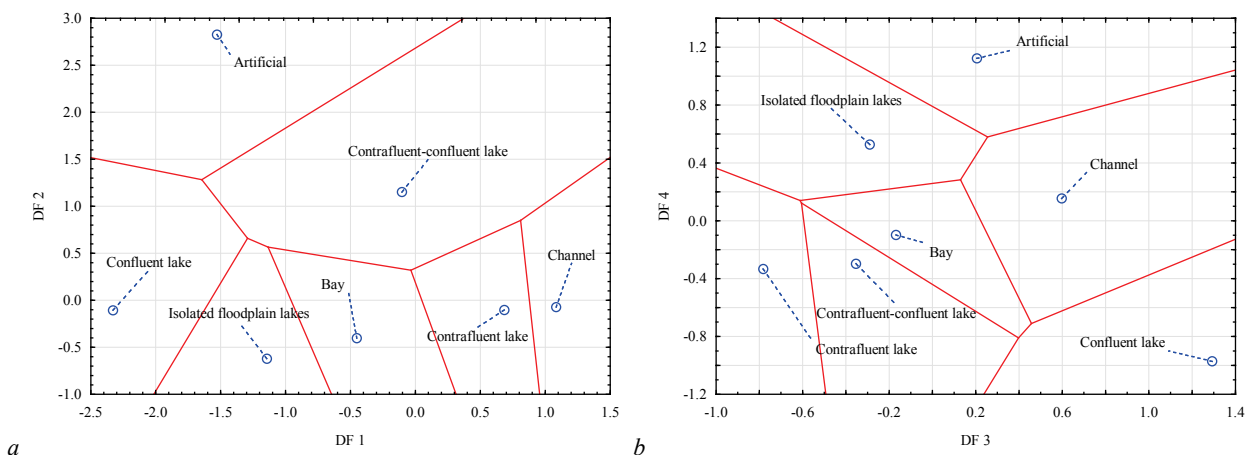


**Fig. 5.** Spatial variation of the slopes of discriminant functions 1–4: discriminant function 1 (a) differentiates water bodies by shoreline development, discriminant function 2 (b) differentiates water bodies by size, discriminant function 3 (c) differentiates water bodies by depth (maximum and average) and shoreline development, discriminant function 4 (d) differentiates water bodies by shoreline development by axis ratio

The location of functional types of water bodies can be represented in the space of discriminant functions (Fig. 6). Voronoi diagrams can be used to show the boundaries of the ranges defined for different types of water bodies. These boundaries show the areas of space where points are closest to a particular type of water body. This is why the range boundaries are rectilinear. The meaning of these ranges is that a point that is located within the range of a particular water body type is most likely to be classified as belonging to that water body type. In the gradient of the discriminant function 1, water bodies are ordered from Canals to Confluent lakes. Discriminant function 2 distinguishes Artificial reservoirs well from all others. Discriminant function 3 is able to distinguish Confluent lakes from Counterfluent lakes. Discriminant function 4 emphasises certain common morphological features of Artificial reservoirs and Isolated floodplain lakes that distinguish them from all others.

*Influence of functional type and morphology of water bodies on species richness of aquatic macrophyte communities.* Functional type

and morphology of the water bodies, as well as time, were able to explain 17% of the variation in species richness of aquatic macrophyte communities (Table 5). Time was able to explain 0.89% of the variation in species richness of macrophyte communities ( $F = 5.0$ ,  $P = 0.002$ ). In May, the species richness of macrophytes was  $17.3 \pm 1.1$  species. In June, this indicator was not statistically significantly different from the level of species richness in May (Planned comparison  $F = 0.38$ ,  $P = 0.53$ ) and amounted to  $17.1 \pm 1.0$  species. In July, there was a statistically significant increase in the diversity of macrophyte communities (Planned comparison  $F = 10.7$ ,  $P = 0.001$ ) to the level of  $19.4 \pm 1.2$  species. In August, the species richness did not differ statistically from the previous site (Planned comparison  $F = 0.32$ ,  $P = 0.57$ ) and amounted to  $19.0 \pm 1.1$  species. The mutual influence of the functional type of water bodies and time was not statistically significant ( $F = 0.1$ ,  $P = 0.99$ ).



**Fig. 6.** Location of functional types of water bodies in the space of discriminant functions 1–4: the boundaries of the areas of the respective functional types are represented as Voronoi diagrams and are the areas where all points are closest to a particular type of water body

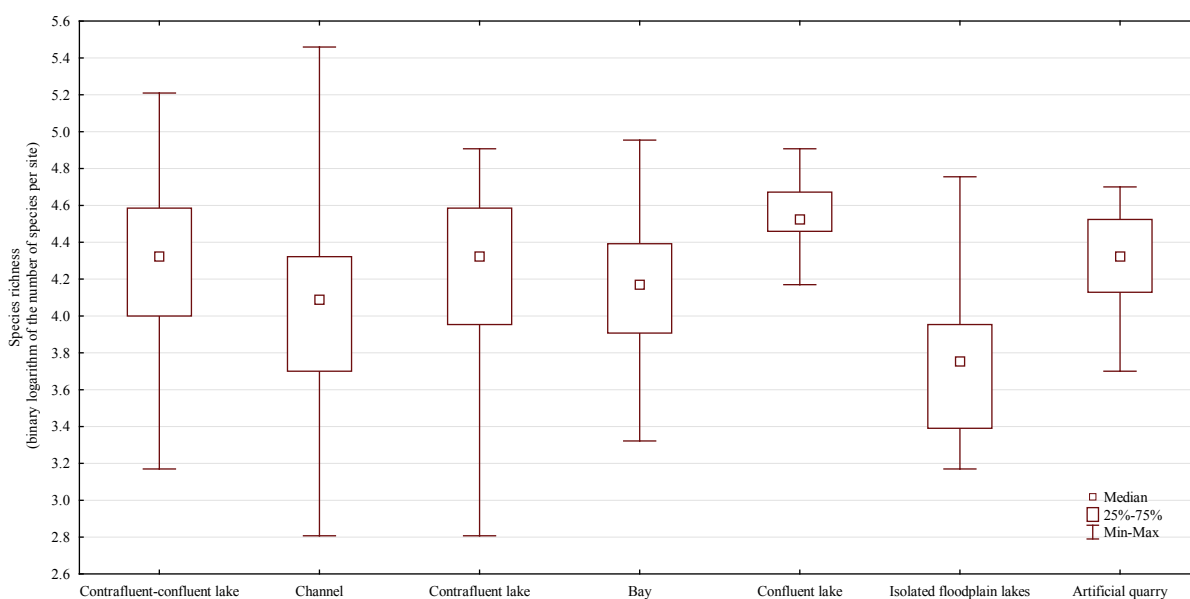
The functional type of the water body was able to explain 7.5% of the variation in species richness ( $F = 21.2$ ,  $P < 0.001$ ). The highest species richness was characteristic of Confluent lakes (Planned comparison  $F = 11.6$ ,  $P < 0.001$ ) and amounted to  $23.8 \pm 1.3$  species (Fig. 6). Species richness in Contrafluent-confluent lakes, Contrafluent lakes, and Artificial water bodies did not differ (Planned comparison

$F = 0.02$ ,  $P = 0.89$ ), but was lower than in Confluent lakes and amounted to  $19.5 \pm 1.2$  species. The species richness of macrophytes in the Channels was lower than in the previous group of water bodies and amounted to  $16.5 \pm 1.1$  species. The lowest species richness of macrophytes was observed in Isolated floodplain lakes (Planned comparison  $F = 50.4$ ,  $P < 0.001$ ) and amounted to  $13.7 \pm 1.0$  species.

**Table 5**

GLM-analysis of the influence of functional type and morphology of water bodies on species richness of aquatic macrophyte communities ( $R_{adj}^2 = 0.17$ ,  $F = 12.7$ ,  $P < 0.001$ )

Effect	Sum of squares	Degree of freedom	Mean sum of squares	F-ratio	P-level
Intercept	6508.2	1	6508.2	39707.8	<0.001
Time period (N)	2.5	3	0.8	5.0	0.002
Functional type of water body (T)	20.8	6	3.5	21.2	<0.001
Mutual effect (N*T)	0.3	18	0.0	0.1	0.99
Water body size (PC1)	18.6	1	18.6	113.4	<0.001
Shoreline development (PC2)	2.5	1	2.5	15.1	<0.001
Axis ratio (PC3)	0.1	1	0.1	0.04	0.84
Fetch (PC4)	1.7	1	1.7	10.1	0.002
Error	291.7	1780	0.2	–	–



**Fig. 7.** Variation of species diversity of macrophyte communities depending on functional types of water bodies:

the abscissa represents functional types of water bodies, and the ordinate represents the number of species in the community: the abscissa is the functional types of water bodies, the ordinate is the species richness (binary logarithm of the number of species per site); square – median, upper and lower rectangle borders – 25% and 75% quartiles, vertical line – minimum and maximum values, circles – outliers;  $n = 54$  for Contrafluent lakes,  $n = 17$  for the Confluent lakes,  $n = 93$  for the Channels,  $n = 38$  for the Contrafluent-confluent lakes,  $n = 50$  for the Bays,  $n = 52$  for the Isolated floodplain lakes,  $n = 8$  for the Artificial water bodies

Morphological features of water bodies were able to explain 8.2% of the variation in species richness of aquatic macrophytes. Among the principal components, component 1 had the greatest influence on species richness and explained 6.7% of the variability of this diversity index. An increase in the principal component 1 scores indicated a decrease in species richness (beta regression coefficient was  $-0.26 \pm 0.02$ ). Principal component 2 was able to explain 0.9% of the variation in species richness. An increase in the principal component 2 scores indicated a decrease in species richness (beta regression coefficient was  $+0.11 \pm 0.03$ ). Principal component 3 did not statistically significantly affect macrophyte species richness. Principal component 4 was able to explain 0.6% of the variation in species richness. An increase in the principal component 4 scores indicated a decrease in species richness (beta regression coefficient was  $-0.07 \pm 0.02$ ).

## Discussion

The Dniprovsko-Orilskyi Nature Reserve is located in an area where the Dnipro River makes a sharp bend, creating conditions for the formation of a wide and complex floodplain, within which there is a complex network of water bodies of different morphology and vary-

ing degrees of connectivity between each other and the Dnipro River channel (Lisovets et al., 2024). Under natural conditions, the floodplain water bodies were fully connected to the Dnipro riverbed during floods almost every year, but after the floods ended, the connection was almost completely lost and the vast majority of water bodies lost their connection to the riverbed (Ruchiy et al., 2024). Sometimes, water bodies dried up and disappeared within a certain period of time after the flood. The vast majority of floodplain water bodies were isolated, and the source of their water supply was groundwater. Under natural conditions, the water sources in the floodplain water bodies were contrasting. During floods, the source of water was water from the Dnipro River channel, while at other times the source of water was mainly groundwater (Zhukov et al., 2024). The role of water supply through canals in the floodplain was secondary, as the vast majority of canals were filled with alluvial sediments during floods. After the creation of the reservoir and regulation of water flow in the Dnipro River, the water regime changed significantly. Flooding has virtually disappeared, and the water level in the reservoir changes very little and gradually throughout the season (Trifanova et al., 2023). The daily variability of the water level in the reservoir is commensurate in amplitude with the seasonal variability of this indicator

(Zymarioieva et al., 2024). As a result, the lowered part of the floodplain remains under the water level all year round, while the raised part of the floodplain is never completely covered with water, as it was under the natural water regime. Visually, the modern part of the Dnipro River channel formally remains a floodplain, with flooding continuing since the reservoir was created. In terms of depth, the part of the Dnipro riverbed closer to the left bank is much shallower than the natural riverbed. Some areas on the left side of the Dnipro riverbed are classified as part of the respective water systems of the Mykolaiv or Tarom escarpments. Typically, the depth in this part of the modern Dnipro River does not exceed 3–4 metres, while in the natural Dnipro River channel the depth can reach 12–15 metres.

The system of modern floodplain water bodies is close to a state of certain thermodynamic equilibrium and exists throughout the year with little dynamics between different years (Yakovenko et al., 2023). This equilibrium is due to a stable annual water level. The sources of water supply for the floodplain water bodies, which are connected to the Dnipro riverbed by channels, are water from the river and groundwater. The contribution of these sources does not change significantly throughout the year. Isolated water bodies do not have contact with the Dnipro riverbed throughout the year, and groundwater remains a constant source of water for them. The constant change in water levels throughout the day, determined by the rhythm of water discharges from the dam, creates a pulsating water level regime in the floodplain water bodies. This regime ensures that the network of channels between the floodplain water bodies remains stationary and that water is constantly exchanged between the water bodies and the riverbed. In the spring, there is sometimes a certain increase in water levels, but this increase is inferior in importance to the water changes that were typical of a natural flood.

Different functional types of floodplain ponds differ in their morphological features and their relationship to water flow, which is an important driver of energy transfer during the season (Raniak & Izakovičová, 2024). These functional types have different genesis, but form the genetic sequence of water bodies and represent different phases of the evolutionary process of water body formation, for which the role of the fluvial factor is crucial. The size of water bodies is the most important aspect of their morphological variability, along with which other morphological features change. The general trend in the variability of species richness of macrophyte communities is its decrease as a response to the increase in the size of floodplain water bodies. The decrease in macrophyte species richness in larger floodplain water bodies can be explained by a decrease in habitat diversity, as large water bodies usually have fewer microhabitats that are essential for different species. In addition, such water bodies are often dominated by certain competitive plant species that displace less adaptive ones. Changes in the hydrological regime, such as increased depth, lower water exchange and reduced water level fluctuations, also reduce the suitability of conditions for many species. An important factor is eutrophication, which is more common in large water bodies and promotes the growth of dominant species that shade and displace others. In addition, ecosystem fragmentation can occur in large water bodies, limiting the reproduction and dispersal of individual species, which together contributes to a decrease in their diversity. The species richness of macrophytes in different functional types of water bodies responds differently to their size. For example, the species richness of macrophytes in such functional types of water bodies as Contrafluent-confluent or Contrafluent lakes, and Bays does not depend on their size. Such water bodies usually maintain a high level of hydrodynamic activity, which ensures constant water exchange and contributes to the enrichment of water with oxygen and nutrients. This creates favourable conditions for the existence of a wide range of species, regardless of the size of the water body. In addition, the diversity of depths and microenvironments in these types of ponds maintains a stable species composition. In Contrafluent water bodies, the constant change in the direction of currents reduces the risk of dominance of certain species, contributing to an even distribution of resources. Bays often have diverse coastal zones that are optimal for many macrophytes, which allows for high species richness regardless of the size of this type of water body.

A strong negative correlation was found between macrophyte species richness and the size of such functional types of water bodies as Canal, Artificial water bodies, and Isolated floodplain lakes, which can be explained by several factors. In Channels, larger sizes are usually accompanied by an enhanced hydrodynamic regime, which creates unstable conditions for macrophytes and complicates their establishment and stable development. In Artificial water bodies, larger sizes are often associated with reduced habitat diversity due to homogeneity of the bottom structure, artificial water level regulation and pollution, which contributes to a reduction in the number of species. In Isolated floodplain lakes, a larger pond size can reduce habitat quality due to increased eutrophication, lack of oxygen in the bottom layers and accumulation of organic matter, which is unfavourable for many macrophyte species. In addition, the isolation of these water bodies limits the inflow of new species, which further worsens the species composition. A greater number of emergent species may participate in the formation of the vegetation cover of small Isolated floodplain lakes due to the greater specific length of the shoreline of small lakes, when their shape does not change significantly with changes in their size.

Functional types of water bodies can be classified according to their response to the opposite dynamics of shoreline development and axis ratio as follows: positive response of the number of species to an increase in the axis ratio and a decrease in the level of shoreline development (Contrafluent-confluent lakes and Artificial water bodies), negative dependence (Confluent lakes), and neutral dependence (Channel, Isolated floodplain and Contrafluent lakes, and Bays). The positive response of the number of macrophyte species to an increase in the axis ratio and a decrease in the level of shoreline development in such functional types of water bodies as Contrafluent-confluent lakes and Artificial water bodies is explained by the improvement of conditions for plant life. Increasing the axis ratio (length to width) provides better mixing of water and enhances water exchange, which contributes to an even distribution of oxygen and nutrients. This creates favourable conditions for the development of various types of macrophytes. Reducing the level of shoreline development, which is characterised by less complexity in its configuration, helps to reduce the isolation of microhabitats. This allows more species to colonise the water body and use resources more efficiently. In artificial water bodies, such changes often contribute to the creation of more stable environmental conditions, which compensates for their initial homogeneity. In contrafluent-confluent lakes, increasing the axis ratio improves water transport and reduces the risk of stagnant zones, promoting the development of a greater diversity of species. Taken together, these factors ensure positive dynamics of species richness in these types of water bodies.

The negative response of the number of macrophyte species to an increase in the axis ratio and a decrease in the level of shoreline development in Confluent lakes is explained by the specific features of these ecosystems. An increase in the axis ratio (length to width) in such water bodies leads to an increase in hydrodynamic activity, which creates less stable conditions for macrophyte development. In elongated water bodies, strong currents can occur, which make it difficult for plants to take root and limit their development. Reduced shoreline development, i.e. reduced complexity of shoreline configuration, limits the variety of microhabitats available, such as shallow water zones, which are key for many macrophyte species. In less fragmented shorelines, there are fewer sheltered areas that are protected from currents and waves, which negatively affects species composition. In Confluent lakes, the role of water inflow from tributaries is important, which can enrich the water body with nutrients, but at the same time leads to increased water flow, which contributes to the mechanical washing away of vegetation. Together, these factors reduce ecosystem stability and lead to a decrease in macrophyte species richness in water bodies with a high axis ratio and a less developed shoreline.

The neutral response of the number of macrophyte species to an increase in the axis ratio and a decrease in the level of shoreline development in such functional types of water bodies as Channels, Isolated floodplain lakes, Contrafluent lakes and Bays is explained by the

fact that these factors have a limited impact on the ecological conditions that define these types of water bodies. In Channels, the stability of species diversity is explained by constant water exchange and hydrodynamic activity, which are dominant factors independent of the shape of the water body or the complexity of the shoreline. In Isolated floodplain lakes, the number of species is largely determined by factors such as eutrophication, isolation and temporal stability, which are independent of the geometric parameters of the water body. In Contrafluent lakes, the constant movement of water due to changes in current directions ensures an even distribution of resources and stable conditions, which minimises the impact of the geometry of the water body on species diversity. In Bays, the number of species is maintained at a stable level due to a wide range of microhabitats that compensate for a decrease in shoreline diversity or changes in the axis ratio.

It should be noted that the species richness of macrophytes decreases with increasing water depth and decreasing shoreline development for Confluent lakes and Bays. No such dependence is observed for other types of water bodies. The decrease in macrophyte species richness with increasing water depth and decreasing shoreline development in Confluent lakes and Bays is explained by the dependence of macrophytes on light, microhabitats and accessibility for rooting. In Confluent lakes and Bays, the diversity of macrophyte species often depends on the presence of shallow water zones where light penetrates to the bottom, providing conditions for photosynthesis. With increasing depth, the number of such zones decreases, which reduces the availability of suitable macrophyte growth sites. Reduced shoreline development reduces the diversity of microhabitats, such as sheltered bays, shallow water and areas with lower currents, which are critical for many species. In Confluent lakes, where there is an active inflow of water from tributaries, the reduction of such sheltered areas can lead to greater exposure to currents that mechanically wash away vegetation. In Bays, the simplification of the shoreline reduces the diversity of shallow water zones and shelterbelts important for macrophytes, especially under wave action. For other types of water bodies, such as Channels, Artificial water bodies, Isolated floodplain lakes or Contrafluent lakes, the species richness of macrophytes is determined by other environmental factors such as water exchange, isolation or eutrophication. In these types of water bodies, microhabitats and shallow water are less dependent on the depth or shape of the shoreline, which reduces the influence of these parameters on species composition.

The species richness of macrophytes decreases with an increase in the ratio of water body axes and a decrease in the level of shoreline development for Contrafluent-confluent lakes. This is because these changes reduce the diversity of habitats and the stability of conditions necessary for macrophyte development. The increase in the axis ratio, i.e. the elongated shape of the water body, leads to increased currents and uneven distribution of water masses, which creates conditions with increased hydrodynamic activity. This makes it difficult for macrophytes to take root and leads to the predominance of only those species that can withstand such conditions, which reduces the overall species richness. Reduced shoreline development reduces the amount and diversity of microhabitats, such as shallow water areas, bays and slow water exchange areas, which are critical for many macrophyte species. In Contrafluent-confluent lakes, these microhabitats are particularly important because they create localised zones with more stable conditions that favour the development of different plant species. Simplification of the shoreline reduces the number of such favourable places, which negatively affects the species composition. Thus, the combination of an elongated water body shape and a less complex shoreline limits the ecological niche for macrophytes, which leads to a decrease in their species richness in such water bodies.

The prospects for future research are centered on a comprehensive examination of the relationships between the morphological characteristics of aquatic systems, their functional classifications, and the ecosystem services they offer. Specifically, it is crucial to investigate the effects of both seasonal and long-term alterations in the hydrological regime on the structure and functionality of floodplain water bodies. The investigation into the effects of climate change on water

level dynamics, eutrophication, and the composition of macrophyte species presents significant potential. Furthermore, it is recommended that research be extended to various geographical regions to facilitate comparisons of water body patterns across diverse climatic and landscape conditions. Increased focus should also be directed towards the development of adaptive water management strategies designed to preserve ecological balance, particularly through the integration of contemporary monitoring and modeling technologies. Additionally, exploring the mechanisms of microhabitat formation in different types of aquatic environments and their contributions to biodiversity maintenance is a promising avenue for research. Such studies will enhance our understanding of ecological processes and yield valuable recommendations for the sustainable utilization and conservation of aquatic ecosystems.

## Conclusion

The study of the functional types and morphological characteristics of water bodies in the Dnipro-Orilskyi Reserve confirmed the key role of these factors in maintaining biodiversity, in particular aquatic macrophyte communities. The highest species richness was found in confluent lakes, due to high hydrodynamic activity, access to nutrients and habitat diversity, while the lowest diversity was observed in isolated floodplain lakes due to limited water exchange and eutrophication. The main factor affecting the species composition of macrophytes is the size of water bodies: with an increase in area, their diversity decreases due to the dominance of competitive species and a decrease in habitats. Other important morphological parameters are the complexity of the shoreline and the ratio of axes, as the elongated shape of water bodies with a less divided shoreline limits the conditions for vegetation development. Changes in the hydrological regime caused by the creation of the reservoir have reduced seasonal fluctuations in water levels, which has affected the structure of ecosystems. The highest level of biodiversity is provided in water bodies with stable water exchange and moderate fluctuations in depth and area. These results emphasise the importance of conservation and adaptive management of floodplain water bodies to maintain their ecological balance and biodiversity. The results are important for understanding the ecosystem services of water bodies, as they highlight the influence of morphological and functional characteristics of water bodies on their ecological role. The diversity of functional types of water bodies and their morphology determine the ability of water bodies to regulate water balance and provide water exchange, which is key to flood and drought protection. The dependence of macrophyte species richness on morphometric parameters such as area, depth and shoreline complexity highlights their role in maintaining biodiversity. The data on the impact of changes in the hydrological regime on ecosystems demonstrate the importance of water management to preserve natural cycles and limit anthropogenic changes. The study highlights the importance of water bodies as a source of numerous ecosystem services, including climate regulation, water purification, biodiversity and recreation, and emphasises the need for sustainable management to preserve them.

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