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integrating riverine and terrestrial systems for a sustainable Danube"

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Plenary section

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The International Association for Danube Research: Past and Future Contribution to the Limnological Research in the Danube River Basin

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Abstract

The International Association for Danube Research (IAD) was established in 1956 under the patronage of the Academies of Sciences in Austria, Romania, and Bulgaria to foster limnological research and cross-border scientific cooperation in the Danube River Basin. Over the years, the IAD has developed into a transnational network of scientists from nearly all Danube countries, with research harmonised across different watercourses and environmental studies.

The evolution of research topics approached by the IAD teams reflects the evolution of aquatic sciences at the international level: from water quality monitoring and taxonomic studies, seeking to advance knowledge in understanding the structure and functionality of the ecosystems, as well as the impact of human activities on the aquatic biodiversity, to systems ecology and integrative environmental topics, methodological innovation and development of digital tools, aiming to provide new model approaches for the sustainable management of the aquatic environment.

In addition, after the establishment of the International Commission for the Protection of the Danube River (ICPDR, 1998) and the adoption of the EU Strategy for the Danube Region (EUSDR, 2011), IAD started to be actively involved in transferring the scientific knowledge into policy actions by providing input through various ICPDR activities in the technical Expert Groups, Joint Danube Surveys expeditions or supporting the implementation of EUSDR through several Task Forces.

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Aware that the sustainable management of the aquatic resources can be achieved only with the wide support of the Danube citizens, in the past decade IAD became more involved in transferring scientific knowledge to the general public through awareness-raising workshops, environmental education and citizen science activities.

Keywords: *freshwater ecology, Danube, nature conservation, science-policy, environmental education*

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Sustainable re-Development: Three Essential Infrastructures for Regional and Global Resiliency

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Abstract

Sustainable development depends on creating a resilient planet serving the needs of both humankind and nature. Climate change is but one of an ensemble of growing environmental stressors that will define the future state of human health and economic well-being as well as the sustainability of the biosphere. Water security is another challenge, which demands reliable water resources, yet their traditional management has broadly failed to avoid environmental degradation and contain infrastructure costs. Using water resources as emblematic of other modern sustainability challenges, this talk assesses the global-scale feasibility of combining natural capital with engineering-based (green–gray) approaches to achieve water security in the 21st century, and leads to the conclusion that a third type of infrastructure – human institutions – is an essential part of creating durable solutions. Policies that support blended green–gray–human approaches offer a pathway to future global water security but will require a strategic commitment to preserving natural capital through wise management. Absent such stewardship, the costs of water resource infrastructure and ecosystem services are likely to rise substantially and frustrate efforts to attain universal, sustainable and resilient water security.

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A Bitter-Sweet Story of the Old Main Channel of the Danube

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Abstract

The Old Danube Channel (a common Slovak–Hungarian stretch of the river, rkm 1852–1812) was born after forced and destructive alteration of the river in 1992, when the Danube was dammed at Čunovo during the implementation of Variant C of the Gabčíkovo-Nagymaros Reservoir System. With more than 100 species of fish, the Danube teems with the greatest species richness among all European rivers. However, the riverine ecosystems have been severely affected by habitat destruction and climate change, followed by biological invasions. As a result, many fish populations in the Danube lack sufficient spawning grounds and habitats suitable for the development and growth of juveniles. The decline in fish abundance in the Danube is alarming; it may have dropped by up to 70% compared to less than a century ago. Regular monitoring of the Gabčíkovo Waterworks since 1991 provides a unique time series of data. In 1999, the structure of fish community started to deteriorate. Over the last 20 years it indicates the worst, 5th class of ecological status (WFD). Nevertheless, thanks to no interventions for over 30 years, numerous diverse microhabitats and mesohabitats have been forming continuously in the Old Danube Channel. A total of approximately 60 species of fish present here nowadays indicates rich biodiversity. As many as 16 of them are listed and protected under Natura 2000. Notwithstanding, non-transparent negotiations between Slovakian and Hungarian politicians, that occurred in 2024, planned damming of the Old Danube Channel at four sites. Such barriers would destroy the 40 km of flowing river with its unique habitats and biota. That would also kill the prospective restoration of trans-Danubian migratory routes for sturgeons and other long-distance migrators. Fortunately, the situation now appears to be improving, creating a welcome opportunity to begin an expert discussion on restoration measures for the shared section of the Danube.

Keywords: *Gabčíkovo-Nagymaros, fish communities, biodiversity hotspot, Natura 2000, migratory route*

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Revitalisation of the Danube Main Channel in the Szigetköz

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Abstract

The Szigetköz border reach of River Danube have been significantly impacted by the implementation of the Gabčíkovo river barrage project. Today, most of the Danube water is diverted to the Gabčíkovo hydropower plant, while the original riverbed and the floodplains receive only 10–20% of the river's discharge. The resulted ecological degradations were counteracted by large scale water supply and water level control infrastructures constructed on the floodplains both in Hungary and in Slovakia. As a result, the typical valuable aquatic and semi-aquatic ecosystems of the floodplains have been revitalised. These measures, however, did not solve the ecological problems of the Danube's main channel, which is still exposed to severe desiccation and eco-hydrological isolation due to the very low water levels. These problems are being addressed by the Insula Magna project, which proposes the construction of four bottom sills in the riverbed with the primary aim of elevating the water levels in the old Danube. Besides revitalising aquatic and semi-aquatic ecosystems in the riverbed, the elevated water levels would also re-establish lateral hydro-ecological connectivity between the river and floodplain for the benefit of an ecologically well-functioning river-floodplain system.

Keywords: *Danube, ecosystems, revitalisation, bottom sills, connectivity*

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Plankton Diversity Responses to Natural and Anthropogenic Impacts in Large Rivers and Oxbow Lakes and their Effects on Ecosystem Functioning

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Abstract

The biodiversity–ecosystem functioning (BEF) theorem predicts that higher diversity enhances ecosystem functioning, such as resource use efficiency. However, increasing evidence shows that community dominance may be a stronger and more consistent predictor than diversity. Because high community dominance often reflects disturbance or competitive exclusion during succession, it can coincide with species loss, challenging a universally positive BEF relationship. In this talk, I present results from a mesocosm experiment under constant mixing and low environmental heterogeneity, conditions somewhat analogous to rivers. Community dominance increased consistently over succession, regardless of species pool size, while neither initial (manipulated number of available taxa) nor realised richness (assessed at the time of sampling) reliably enhanced resource use efficiency. I then extend these findings to natural river plankton using both classical taxonomic and eDNA data across phytoplankton and the phytoplankton–zooplankton interface, further supporting the key role of community dominance in resource use efficiency. Finally, I show how river regulation can reshape lateral habitats such as oxbow lakes, altering lake morphometry, connectivity, and local environmental heterogeneity, with cascading effects on biodiversity and functioning. Overall, community dominance over diversity seems to emerge as a more robust and systematic predictor of resource use efficiency in pelagic systems.

Keywords: *community dominance, eDNA, fluvial ecosystem, succession, taxonomic richness*

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Conservation and Restoration Planning for Freshwater Biodiversity in the Danube Basin within and beyond Protected Areas

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Abstract

Freshwater biodiversity in the Danube Basin is under increasing pressure from hydromorphological alterations, land use changes and intensifying climate extremes. Although the basin hosts an extensive network of protected areas, conservation outcomes remain limited because ecological processes depend on connectivity extending beyond site boundaries. The presentation integrates the requirements of the EU Nature Restoration Regulation, emphasising its obligation to restore degraded freshwater ecosystems and improve connectivity at basin scale. It argues for integrated, multi-level planning that combines top-down policy frameworks with bottom-up, stakeholder-informed implementation. Using examples across multiple spatial scales, from basin-wide prioritisations to floodplain and site-level case studies, the talk highlights how conservation priorities shift with scale, data, and methodology. Coarse-resolution planning may misrepresent local ecological value and restoration feasibility, while fine-scale analyses reveal critical habitats and restoration opportunities, including side arms and floodplain reconnections. Ultimately, freshwater conservation requires moving beyond static protected areas toward process-based management that restores hydrological connectivity while addressing socio-economic constraints and increasing drought pressures.

Keywords: *connectivity, NRR, spatial optimisation, water management, landscape design*

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Nature-Based Solutions for Climate Adaptation in the Tisza River Plain

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Abstract

The effects of climate change are primarily perceived through the increasing extremes observed in water management. We must expect rising average temperatures, more intense evapotranspiration, more frequent heat waves, droughts and less frequent but more intense precipitation events. All of this reduces the amount of water available for habitats and human use in the landscape. The situation is particularly severe in the Tisza River Plain in Hungary. The accumulating lack of rainfall is causing serious damage to agriculture and natural habitats. Given these trends, a water management model that focuses on the rapid drainage of floodwaters and inland waters is unsustainable. We can slow the depletion of groundwater and promote its recharge by nature-based solutions: 1. retaining some of the floodwater from rivers in landscapes by reconnecting floodplains to the river; 2. retaining inland waters on site rather than draining them; 3. promoting infiltration by soil regenerating farming practices. This requires land, which also means that some of the low-quality arable land must be converted into grasslands, wetlands, or forests, depending on local conditions, thereby increasing biodiversity and creating mosaic-like landscapes. In this presentation, we will review the key areas for change in water management, land use, industrial and residential water use and public awareness necessary to mitigate the effects of climate change in the Tisza River Plain.

Keywords: *nature-based water retention, land use change, climate adaptation, resilience*

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New Challenges of River and Landscape Management in the Middle Danube Basin

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Abstract

Flooding used to be a natural feature of the Carpathian Basin, where about 25% of the land functioned as floodplain, shaping settlement patterns, transport, population distribution, and economic activity. After the Industrial Revolution, large-scale river regulation enabled intensive agricultural expansion through channel straightening, dike construction, and drainage. While this reduced flood risk and supported economic growth, it caused major ecological losses, including the destruction of nearly 30,000 km² of wetlands and natural habitats. Although these interventions reflected the best available knowledge of their time, climate change and soil degradation have exposed their limitations recently. Lowland areas of the basin now face increasingly unstable hydrological conditions, with more frequent water-related extremes such as severe droughts and flash floods, as well as declining river discharges alongside rising flood levels. These changes have transformed the goals of water management. Rather than creating new economic benefits, current efforts focus on minimising future damage under worsening environmental conditions. Modern water management has become inherently multidisciplinary, requiring the integration of natural and social sciences within an expanding regulatory framework. Large-scale initiatives aimed at restoring landscape functions and maintaining essential ecosystem services therefore depend on robust, adaptive solutions supported by strong socio-economic research and planning.

Keywords: *river training, landscape hydration, climate change*

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Section 1

Anthropogenically induced changes

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Modelling Long-Term Riverscape Evolution in the Danube Floodplain National Park (Austria) – Effects of Internal and External Perturbations

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Abstract

The Danube's discharge in the National Park is highly variable. Average flow typically ranges between 1,500 and 1,900 m^3/s. Low flow levels can drop to 600–900 m^3/s, while 100-year flood events can reach 8,500 – 11,000 m^3/s. Due to climate change, there is an overall decreasing trend in growing season (April–September) streamflow, while winter volumes are slightly increasing due to changing precipitation patterns. Snowmelt-driven spring floods are occurring earlier, and often more pronounced, in the year due to reduced mountain snow storage. While major floods are rare due to river regulation measures, extreme precipitation (like the 2002, 2013 or 2024 events) can cause rapid regional flooding with significant geomorphic effects.

The National Park contains the last major "free-flowing" stretch of the Danube in Austria (36 km), yet it faces significant structural and ecological challenges. A major deficit in bedload sediment induced by upstream dams causes the riverbed to deepen progressively. Management combats this by dumping gravel to stabilise the bed. Paradoxically, while the main bed level sinks, the floodplains (including present side arms) are rising due to overbank sedimentation, fragmenting vital floodplain aquatic habitats and increasing terrestrialisation trends.

Within the EU-funded "DANube SEdiment Restoration (DANSER): Towards deployment and upscaling of sustainable sediment management across the Danube River basin" project one essential project task is to model the long-term hydro-geomorphic effects of different types of river(scape) management and restoration efforts, such as the reconnection of side-channels and the removal of embankments. In this presentation, we will

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highlight the results of different flood and management scenario runs using the 2D landscape evolution model CAESAR-Lisflood. We will focus on complex hydro-geomorphic responses to various external and internal perturbations, with a particular focus on the effects of flooding, river engineering, and restoration efforts, as well as related long-term consequences for lateral connectivity, riverscape evolution and potential implications for aquatic biodiversity.

Keywords: *sediment dynamics, riverscape evolution, river engineering, river restoration*

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Hydrological Connectivity Mediates Water Quality and Deep-Water Anoxia in Tisza River Oxbow Lakes

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Abstract

This study investigates hydrological connectivity as a driver of morphometric and functional differences among 40 oxbow lakes along the Tisza River (Hungary), assessed by comparing floodplain and flood-protected sites sampled in summer 2025. Trophic analysis revealed eutrophic to hypereutrophic conditions across all lakes, driven by extreme total phosphorus concentrations. Primary production was not phosphorus-limited; rather, phytoplankton growth was constrained by light limitation and the interplay between benthic and pelagic eutrophication in response to lake morphometry. Multivariate analyses demonstrate that lateral connectivity significantly impacts the hydrochemical environment. Lacking periodic river flushing, protected oxbows acted as evaporative sinks with significantly higher electrical conductivity and pH. Furthermore, linear mixed-effects modelling revealed that hydrological isolation dramatically accelerates deep-water deoxygenation. Although surface dissolved oxygen did not differ between lake types, flood-protected lakes exhibit a significantly steeper trajectory of oxygen loss with depth. Our findings indicate that hydrological isolation fosters thermal stratification and prolonged water residence time, driving enhanced organic matter accumulation and severe deep-water anoxia. Ultimately, lateral connectivity and lake morphometry of the highly modified oxbow lake ecosystems underpin their susceptibility to legacy nutrient loading and extreme oxygen depletion.

Keywords: *eutrophic lakes, floodplain isolation, hydrological connectivity, hypoxia, Tisza River*

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Recent Trends in Ponto-Caspian Peracarid (Crustacea) Invasions in the Danube River

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Abstract

Ponto-Caspian species naturally occur in the Lower Danube. However, human activities greatly facilitated their colonisation of the upstream river sections. Their spread accelerated, especially after the opening of the Danube–Main–Rhine Canal in the 1990s.

By the 2010s, Ponto-Caspian species invasions appeared to slow down as the majority of the lithophilous species had already become established, while the psammo-pelophilous species (i.e. preferring sandy-muddy substrates) showed little invasion success.

The standstill was later broken by the emergence of *Paramysis lacustris* in the Tisza River, which likely facilitated its subsequent establishment in the middle and upper Danube sections.

Recently, *Pontogammarus robustoides*, another psammo-pelophilous species has also colonised the Tisza River, indicating the continued spread of Ponto-Caspian species within the Danube catchment. However, the most recent Ponto-Caspian invader in Europe, *Chelicorophium maeoticum* seems to follow a different geographical pattern. While previously invasions were mainly facilitated by shipping along interconnected inland waterways, this species likely arrived directly in the Rhine estuary by sea cargo ships. Nevertheless, its "backward" spread within the Rhine–Danube system, as well as towards other regions, can be anticipated.

Keywords: *Amphipoda, Isopoda, Mysida, Southern invasion corridor*

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The Kilia Delta of the Danube River as a Key Transit Zone for Migratory Fish Species

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Abstract

The Kilia Delta of the Danube River is one of the crucial transit zones for migratory fishes in the lower part of the river basin. It ensures the life cycles of many anadromous and semi-anadromous species. At the same time, anthropogenic pollution of water bodies, overfishing, and the invasive species' spread pose significant threats to the preservation of migration routes and fish biodiversity.

Actually, up to 90 fish species of 18 families may potentially be found in the Kilia Delta region. Of these, 29 species are listed in the Red Book of Ukraine (32.2%), 16 species are included in Resolution 6 of the Bern Convention (17.8%), and 8 species are non-native (8.9%).

The Kilia Delta is of special importance for migratory fish species, as it provides their migration routes, feeding, and the growth of juveniles. This applies primarily to sturgeons *(Acipenser nudiventris, Acipenser sturio, Acipenser gueldenstaedtii, Acipenser stellatus, Acipenser ruthenus, Huso huso),* salmonids *(Salmo labrax),* herrings *(Alosa pontica, Alosa tanaica),* eels *(Anguilla anguilla),* and cyprinids *(Chondrostoma nasus, Barbus barbus).* Beside its transit function, this part of the Danube Delta plays an important role as a feeding and spawning ground for many rare and locally vulnerable fish species.

Preserving the functional importance of the Kilia Delta of the Danube as a transit zone for migratory fish species requires a comprehensive approach that should include the protection of key habitats, maintaining ecological connectivity in waterways, reducing human impact, and strengthening efforts to combat poaching.

Keywords: *The Kilia Delta of the Danube, biodiversity, rare species, migratory fish species*

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Restoration of Pannonian Lowland Rivers

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Abstract

The Nature Restoration Regulation is mainly about understanding what still needs to be done and what has already been done. By 2030, at least 25,000 kilometres of rivers have to be renaturalised and restored to a free flowing nearly natural state in the European Union. Restoration projects on rivers in the Pannonian region primarily focus on their potamal stretches. Most of these projects are new and challenging because they involve a wide range of interdisciplinary requirements, including geomorphology and sediment-ology, limnology and floodplain ecology, as well as hydrology, climate change and water risk management.

The presentation highlights three examples of medium-sized rivers: two completed Interreg projects and one additional project currently being planned by the regional government. These are the Thaya, the Rába (Raab), and the Lajta (Leitha), the latter two being shared with Hungary. At the Thaya and the Rába, the main measures focused on the reconstruction of meanders and oxbow lakes, while for the Lajta the vision is the creation of a new riverbed. Water retention capacity and river morphology are to be restored in order to support biological connectivity and diversity and to improve the conservation status of habitat types, such as floodplain forests. Water management and ecological planning must be integrated and further developed to meet future needs of both nature and society.

Keywords: *transboundary river management, fluvial restoration, nature-based solutions, sediment management, ecological resilience*

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The Russia–Ukraine War as a Threat to the Ecological Conditions of the Lower Danube River

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Abstract

The large-scale Russian aggression against Ukraine poses a serious threat to the ecological conditions of the Lower Danube River. During the war, numerous incidents involving ships and port infrastructure have caused water contamination and created other environmental risks. The first such case occurred on the night of 23–24 July 2023, when a Romanian vessel sustained minor damage during a Russian attack on the Ukrainian port of Reni. On 28 August 2025, a Russian unmanned surface vessel sank the Ukrainian warship in the Danube Delta. On 16 November 2025, a Russian drone struck the Turkish-flagged LPG tanker. The fire on board forced the evacuation of local residents from the Romanian border village of Plauru, located on the right bank of the river. A civilian Panamanian-flagged vessel and the port infrastructure of Izmail were damaged during a Russian strike on the night of 13–14 April 2026.

Importantly, the main flight routes of Russian missiles and unmanned aerial vehicles targeting Ukrainian facilities pass over the territory of the Danube Biosphere Reserve. The interception of these aerial vehicles is often accompanied by debris falling into the floodplain, frequently causing fires. A large-scale fire broke out as a result of a Russian attack on 2 January 2026. Following the crash of a downed unmanned aerial vehicle, floodplain vegetation burned over a total area of more than 10,000 hectares. Such events have become increasingly frequent within the reserve.

Another threat to the river ecosystem is the transportation of oil by tankers. Usually, one or two such vessels are present in this section of the river, particularly near the ports of Galați and Giurgiulești. Additional risks are posed by oil storage facilities located in ports.

Keywords: *war, threat, the Danube River*

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Section 2

Monitoring of aquatic species and habitats

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False Transparency: When Clear Water Hides Light Limitation for Submerged Macrophytes

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Abstract

Submerged macrophytes, as primary producers, depend on adequate photosynthetically active radiation (PAR) within the water column. Our study evaluated vertical PAR profiles measured in May 2025 at seven floodplain lakes and channels of the Danube Delta Biosphere Reserve (Romania), focusing on depths providing optimal light conditions for macrophyte growth rather than solely on euphotic depth. Results indicate that light availability at the macrophyte canopy is a more ecologically relevant indicator of habitat quality than water surface transparency alone.

Field observations revealed widespread accumulations of filamentous algae forming dense veil-like structures and floating mats. These algal layers create a phenomenon of "false transparency", whereby visually clear water overestimates the amount of light reaching submerged vegetation. Macrophytes including *Trapa natans*, *Ceratophyllum demersum*, *Stratiotes aloides*, and the invasive *Elodea nuttallii* were frequently covered by epiphytic filamentous algae. Such filamentous algae overgrowth reduces PAR availability, limits photosynthesis, and increases the risk of macrophyte suppression.

The prevalence of filamentous algae suggests an ongoing ecosystem imbalance and highlights the limitations of transparency-based assessments. Restoration efforts should prioritise reducing nutrient enrichment and promoting resilient macrophyte communities capable of persisting under low-nutrient conditions. Only macrophytes that are free from excessive filamentous algal overgrowth can restore open-water transparency as a reliable indicator of ecological quality in the Danube Delta.

Keywords: *underwater light climate, eutrophication pressure, habitat degradation, wetland restoration, ecosystem resilience, floodplain limnology*

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Evaluating the Effects of Wetland Restoration Using Sentinel-2 Data and LSTM Models: A Case Study of Obedska Bara, Serbia

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Abstract

Wetlands along the Danube–Sava corridor require robust monitoring frameworks to distinguish the effects of restoration measures from natural hydro-climatic variability. This study presents a Sentinel-2 and Long Short-Term Memory (LSTM) based framework for assessing restoration outcomes in the Special Nature Reserve Obedska Bara, Serbia. The evaluated restoration measure involved the removal of accumulated sediment from an old meander through dredging, with the aim of revitalising the aquatic habitat.

Interpolated NDVI, NDMI and NDWI spectral indices derived from Sentinel-2 imagery were combined with daily air temperature, precipitation, water temperature and water-level data, as well as indicators of temperature extremes. Pre-restoration data from 2017 to 2018 were used to train the LSTM models. Following the restoration works carried out in 2020, post-restoration satellite observations from 2021 to 2024 were compared with modelled reference scenarios representing conditions in the absence of restoration.

The models achieved Nash–Sutcliffe Efficiency values of +0.63 for NDVI, +0.54 for NDMI and +0.45 for NDWI. The RMSE-to-standard deviation ratios fell within the "satisfactory" range defined by Moriasi and colleagues in 2007, while Willmott's index of agreement exceeded 0.82 for all three indices. Following restoration, observed NDMI and NDVI values were higher than the corresponding modelled reference values,

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indicating maintained or improved vegetation moisture status and activity. In contrast, lower observed NDWI values suggested a potentially unfavourable hydrological signal, highlighting the need to restore lateral connectivity with the Sava River.

The proposed framework supports adaptive wetland management by integrating Earth observation data, hydro-meteorological variables and machine-learning methods to provide an evidence-based assessment of restoration outcomes.

Keywords: wetland restoration, Sentinel-2, LSTM, Obedska Bara, vegetation indices

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Assessing Reed Carbon Stocks to Support Restoration in the Danube Delta

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Abstract

Wetlands are among the most effective natural carbon sinks, yet their carbon sequestration potential remains insufficiently quantified and integrated into restoration and management strategies. Within the DaWetRest project, a carbon sequestration assessment was conducted in the Caraorman–Roșu–Puiu lakes sector of the Danube Delta Biosphere Reserve, focusing on reed-dominated ecosystems *(Phragmites australis)* and their contribution to climate mitigation, biodiversity conservation, and sustainable resource use. A multi-season remote sensing approach based on Sentinel-2 imagery and NDVI analysis was developed to map reed distribution and estimate biomass dynamics between April and October 2025. Seasonal thresholds specific to reed habitats were established and validated through literature review, comparative analyses, and field observations. The analysis identified 9,061 ha of reed beds, representing a significant carbon pool within the study area, with an estimated aboveground carbon stock exceeding 86,500 Mg C. Beyond carbon accounting, the study demonstrates how sustainable reed management can support nutrient uptake, sediment retention, water quality improvement, and habitat preservation while creating opportunities for circular bioeconomy development through reed valorisation. The proposed methodology provides a replicable framework for integrating carbon sequestration assessment into wetland restoration planning, supporting climate resilience, adaptive ecosystem management, and long-term policy objectives for nature-based solutions across European wetlands.

Keywords: *carbon sequestration, reed, remote sensing, wetland restoration, Danube Delta*

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Monitoring of Aquatic Invasive Alien Species in Bulgaria in the Frame of the Joint Danube Survey 5

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Abstract

Prevention, including regular surveys, early detection, and rapid response, is the most efficient and cost-effective strategy to address aquatic invasive alien species (IAS). Monitoring of the aquatic IAS along the Bulgarian sector of the Danube River has been conducted under certain national monitoring programmes (WFD 2000/60/EC, Regulation [EU] 1143/2014) and research projects. This report presents results of IAS monitoring along the Bulgarian sector of the Danube River within the framework of Joint Danube Survey 5 (2025). A total of 23 sites were sampled in August 2025, of which 11 sites on the Danube River, 3 sites at the Danube tributaries, and 9 sites at adjacent water bodies (lakes, canals, reservoirs). Benthic macroinvertebrates and fish were collected using a sieve, triangular dredge, dip net, beach seine nets, LiNi traps and gill nets. Citizen science contributions and observation of fishermen's catches were also used. A total of 17 alien and invasive alien species were recorded: one aquatic plant, 7 benthic macroinvertebrates, and 9 fish species, including 7 IAS of Union concern *(Elodea nuttallii, Faxonius limosus, Pseudorasbora parva, Ameiurus melas, Gambusia holbrooki, Lepomis gibbosus* and *Perccottus glenii).* The oriental river prawn *Macrobrachium nipponense,* a new invader in the Danube River, was the most frequently found and abundant species in the catches.

Keywords: *Danube River basin, biological invasions, alien invertebrates, alien fish, IAS survey*

Acknowledgements: This study and presentation were conducted within the framework of JDS5 and supported by the Bulgarian Academy of Sciences and Czech Academy of Sciences (bilateral agreement, project No. IC-CZ/07/2025-2026) and the EU funded DANUBE4all project.

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Establishing Reference Conditions for Benthic Invertebrate Fauna to Assess Ecological Status of Water Bodies in the Lower Danube

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Abstract

A typological analysis of the water bodies of the lower Danube was carried out based on the taxonomic structure of benthic macroinvertebrate fauna. To identify similarities between communities of different types of water bodies, hierarchical cluster analysis was applied. The analysis enabled to identify distinct typologically homogeneous groups of water bodies reflecting common hydrological, geochemical, and biotopic conditions, as well as to reveal differences between the "young" Kiliya delta of extension and the more mature Sulina delta of infill. According to the requirements of the national methodology and the EU WFD, an updated typology of water bodies in the Lower Danube has been proposed, comprising 7 types: the main river channel, active and dying-out channels of the Kiliya Delta, channels of the Sulina Delta, lakes and freshwater bays, as well as mesohaline bays.

It has been established that reference conditions should be determined by the type-specific structure of benthic communities. For channel ecosystems, the reference communities are rheophilic with high portion of Gammaridae, Dreissenidae, and oxyphilic Chironomidae, whereas communities of active channels are characterised by maximum taxonomic diversity and polydominant structure. For dying-out channels and lakes, the reference communities are stable, moderately diverse, without the dominance of tolerant oligochaetes and chironomids, and for mesohaline bays – stable brackish-water complexes.

Keywords: *benthic invertebrate fauna, reference conditions, water body typology, Lower Danube, ecological status assessment*

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Direct Observation and Monitoring of Aquatic Ecosystems in the Danube Region (DOME) with Special Emphasis on Predicting the Swarming of the Danube Mayfly Ephoron virgo

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Abstract

The new citizen science programme, DOME, focuses on collecting occurrence data of key native and non-native species across the Danube River Basin, helping to fill major gaps in biodiversity observational data across large spatial and temporal scales (https://dome.ecolres.hu). At launch, the project has been linked to iNaturalist (https://tinyurl.com/4vx-5hhrs) also recording the occurrence of the Danube mayfly *(Ephoron virgo),* a key indicator species of river water quality. A central goal is to improve the prediction of Danube mayfly swarming events, which typically occur in late summer but vary in timing among years. The environmental drivers of this variability are not yet fully understood. We analysed how factors such as water temperature and river discharge influence swarming onset. Using publicly available webcam imagery combined with environmental datasets, we examined correlations between observed swarming dates and the above-mentioned environmental parameters. Preliminary results suggest that water temperature and discharge, measured months in advance of swarming, provide meaningful predictive power for estimating the time of the next swarming. The potential for early forecasting can support better planning of public events related to the spectacular swarming, help organisers of summer events minimise disturbance to Danube mayfly swarming and help optimise operation schedules of existing mayfly-protection lights installed on bridges (Tahitótfalu, Budapest).

Keywords: *mayfly, swarming, prediction, temperature, discharge*

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Fifty Years of Ecosystem Monitoring at the Biologische Station Neusiedler See

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Abstract

Long-term ecological research (LTER) is essential because it 1. reveals slow environmental changes and long-term trends that cannot be detected in short-term studies; 2. improves our understanding of ecosystem responses to climate change, land-use change, and management interventions, and 3. provides a robust scientific basis for conservation, biodiversity protection, and evidence-based environmental policy.

The Biologische Station Neusiedler See is situated at Lake Neusiedl in Illmitz (Austria) and is a service department of the provincial government of Burgenland. With more than 50 years of experience in basic and applied ecological research, the station is located in the heart of the Neusiedler See – Seewinkel National Park. It hosts accredited chemical and microbiological laboratories for water analysis and provides expertise in water quality assessment, ecosystem monitoring, and applied environmental research.

Together with its monitoring sites and partners, the station maintains long-term datasets on meteorology, limnology, lake chemistry, entomology, botany, air quality, and carbon fluxes. Particular research priorities include the long-term monitoring of Lake Neusiedl's water quality, bird surveys, the ecological effects of long-term reed management, and the biodiversity of insect communities. These activities contribute to understanding ecosystem dynamics and support evidence-based conservation and management of this internationally important wetland ecosystem.

Keywords: *ecosystem dynamics, anthropogenic pressures, ecological indicators, conservation management, cross-sectoral environmental assessment*

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From Data Gaps to Monitoring: Challenges and Opportunities in Monitoring the Sterlet (Acipenser ruthenus) Population

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Abstract

Maintaining good ecological status while supporting the multifunctional use of rivers is a central objective of water management. The sterlet *(Acipenser ruthenus),* a migratory sturgeon species, is a key indicator for sustainable river management due to its dependence on longitudinal connectivity, suitable channel morphology, and stable water quality. In Hungary, however, no dedicated monitoring system exists for sterlet populations; available knowledge relies primarily on historical commercial fishery data from the mid-20th century. These data indicate a marked decline in catches across all major river systems by the early 21st century, leading to a nationwide ban on catching sterlet in 2014. As a result, empirical information on sterlet population dynamics has been limited for over a decade.

Recent international initiatives provide new opportunities to address this gap. The MonStur project under the Interreg Danube Region Programme aims to establish a harmonised, transnational sturgeon monitoring system, including standardised methods and a shared database. In addition, the Horizon Europe SWIM project will implement a telemetry-based monitoring system along the Danube upstream of Budapest and in the Szigetköz region, interoperable with existing Slovak infrastructure. This cross-border approach is expected to enable the tracking of sterlet migration over a 200 km river section, contributing to a more comprehensive understanding of population status and informing evidence-based water management strategies.

Keywords: *sturgeon, bioindicator species, telemetric monitoring, cross-border cooperation, Danube*

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Frequency-Domain Characterisation of Water Quality Dynamics: A Signal-Theoretic Framework for Monitoring Network Design in Danube Basin Watercourses

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Abstract

Continuous in-situ monitoring systems generate high-frequency water quality time series encoding dynamics across multiple temporal scales. Translating this information into rational monitoring network design – specifically, defensible parameter-specific sampling frequencies – remains a methodological gap in routine practice.

This study applies frequency-domain analysis (Fast Fourier Transform, power spectral density estimation) to continuous multi-parameter datasets from multiple watercourses in the Danube basin, including the Koppány Stream, the Hosszúréti Stream, and the Ráckevei-Soroksári-Danube branch. The latter is a hydraulically managed, nutrient-enriched lowland channel that provides contrasting conditions to the small and medium-sized streams, which are subject to high urban and agricultural pressures, broadening the applicability of the framework across water body types. The online monitoring stations were installed in different periods between 2022 and 2025. Each time series is at least two years long. Measured parameters include water temperature, pH, dissolved oxygen, nitrogen forms, and turbidity.

Stationarity of the data sets is assessed using formal statistical tests prior to spectral analysis; where it cannot be established, the implications for frequency-domain inference are examined explicitly. Minimum sampling intervals are derived from the Nyquist–Shannon theorem.

The presentation will discuss how spectral structure and derivable minimum sampling frequencies vary between parameters, water body types, and seasons, and will evaluate

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the conditions under which the framework yields robust, practically applicable guidance for monitoring network design.

Keywords: *online water quality monitoring, sampling frequency, FFT, Nyquist*

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Section 3

Protected areas and biodiversity conservation

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Hydrological Connectivity Governs Functional Trait Patterns and Metacommunity Assembly in Danube River–Floodplain Fish Communities

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Abstract

River–floodplain systems are highly dynamic ecological networks where hydrological connectivity plays a central role in shaping biodiversity patterns and ecosystem functioning. However, a mechanistic understanding of how connectivity regulates functional trait patterns and metacommunity assembly remains limited.

Here, we combine two complementary analyses based on environmental DNA (eDNA) data from Austrian and Hungarian Danube floodplains (2021–2023). We first examine how fish community functional traits respond to a gradient of lateral hydrological connectivity, revealing consistent shifts: isolated habitats promote convergence, highly connected habitats enhance divergence, and intermediate connectivity maximises temporal variability.

We then apply a process-informed metacommunity framework to disentangle the mechanisms underlying these patterns. By integrating spatial, environmental, and biotic components in a path modelling approach, we quantify the roles of dispersal, environmental filtering, stochasticity, and species interactions in shaping community structure. Connectivity emerges as a central factor, structuring beta diversity both directly and indirectly through its influence on environmental heterogeneity and dispersal.

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By linking functional trait responses with metacommunity processes, this study provides a unified understanding of how connectivity governs biodiversity organisation in floodplain landscapes, with implications for conservation and river basin management.

Keywords: *hydrological connectivity, metacommunity, functional traits, eDNA, floodplain*

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The Danube Delta and the North-West Black Sea Region as Refugia of Alien Species of Fishes and their Parasites

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Abstract

During 2020–2023, parasitological investigations of four fish species non-native to European freshwater ecosystems *(Syngnathus abaster*, *Atherina boyeri*, *Lepomis gibbosus*, *Pungitius platygaster)* were conducted across different sections of their natural and introduced ranges (the Black Sea, estuaries, and freshwater sections of the Danube, Dnipro, and Dnister rivers; over 50 parasite species recorded, more than 10 localities in the Danube Delta). Using a novel approach of ecological categorisation of parasites, we demonstrate that the structural and functional organisation of local parasite communities of non-native fish depends primarily on the ecological characteristics of the inhabited water bodies. The ecological-parasitic structure differed significantly between the freshwater Dnipro populations (cluster 1) and the Danube–Dnister-estuarine populations including the Black Sea Odesa Gulf (cluster 2). All indicator parasite species – ciliate *Trichodina partidisci,* monogenean *Gyrodactylus ginestrae,* monogenean *Onchocleidus dispar,* ciliate *Apiosoma gasterostei* – were only recorded in cluster 2, supporting the recognition of the Danube Delta and the north-western Black Sea region as a primary refugium and source of alien aquatic species expanding into Ukrainian and European inland waters.

Keywords: *alien species, parasites, Danube Delta*

Acknowledgements: Supported by the NRFU project "Development of scientific backgrounds of comprehensive monitoring and threats of distribution of invasive fish species by riverine systems and transitional waters of Ukraine (based on parasite, population and genetic markers)" (#2020.02/0171)

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Lateral Hydrological Connectivity is the Main Driver of Macroinvertebrate Communities in a Natural Floodplain along the Danube River

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Abstract

River-floodplains are among the most diverse and productive ecosystems primarily influenced by disturbances, such as lateral hydrological connectivity (LHC). LHC means the connection between the main channel and the differed water bodies in the floodplain that varies from constant to periodic. Our study investigated the primary drivers of aquatic macroinvertebrate community composition in floodplain habitats of Gemenc and the northern part of Béda-Karapancsa Nature Reserve. We examined shifts in community structure, as well as the proportions of non-native and protected species along a connectivity gradient. Our results revealed that sampling occasion exerted a predominant effect on community composition, highlighting the temporal dynamics of the studied system. Beyond that, also the LHC had significant effect, what was consistent across the four sampling occasions. Regarding biodiversity metrics (abundance, richness, Shannon diversity, and evenness), only taxonomic richness exhibited a unimodal response to connectivity in the aggregated dataset, providing support for the Intermediate Disturbance Hypothesis. However, the response of these metrics varied between linear and unimodal patterns when analysed for individual sampling occasions. Finally, the positive relationship between connectivity and the proportion of non-native species and individuals suggests that low-connectivity or isolated water bodies may serve as environmental filters due to their lentic characteristics.

Keywords: *lateral hydrological connectivity, river-floodplain, alpha diversity, macroinvertebrate community*

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Effects of Lateral Hydrological Connectivity on the Relative Abundance of Water Frogs (Pelophylax spp.) and Common Toads (Bufo bufo) using eDNA Surveys

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Abstract

Riverine floodplains sustain diverse amphibian communities by providing key breeding and refuge habitats, where lateral hydrological connectivity (LHC) shapes local environmental conditions. This study investigated how LHC influences the two most abundant amphibian taxa in the Danube River floodplain: water frogs (*Pelophylax* spp.) and the common toad *(Bufo bufo)*. Using environmental DNA (eDNA) surveys at 30 sites along an LHC gradient, we estimated species relative abundance and assessed habitat structure, vegetation cover, and the physical and chemical characteristics of water bodies. Structural equation models (SEM) were applied to disentangle the direct and indirect effects of hydrology on amphibian occurrence through these environmental variables. LHC showed no direct effect on the abundance of either species; however, significant indirect, species-specific pathways were detected. For *Pelophylax* spp., hydrology had a negative indirect effect mediated mainly by vegetation cover and water body physicochemical conditions. In contrast, *B. bufo* responded primarily through changes in habitat structure, with similar indirect negative effects. These results demonstrate that alterations

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in hydrological connectivity can affect amphibian communities differently depending on species-specific ecological requirements. Understanding these indirect pathways is essential for predicting the consequences of river regulation and for improving conservation strategies in floodplain ecosystems.

Keywords: *environmental DNA, metabarcoding, water frog, common toad, hydrology, wetland*

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Towards Linking Pelagic Food Web Complexity and Ecosystem Functioning in the Middle Section of the Danube River

Ghoufrane Derhy,[1] Flórián Tóth,[1] Tamás Felföldi,[2, 3] András Hidas,[2] Junyao Gu,[1] Imola Tenorio-Baigorria,[1] Vũ Đức Thịnh Nguyễn,[1, 4] András Abonyi[1]

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Abstract

Linking food web ecology and biodiversity-ecosystem functioning (BEF) research is essential for better understanding how diversity mediates ecosystem functioning in a multi-trophic context. Freshwater ecosystems, especially large rivers, remain understudied in this context, including the Danube River. Therefore, we analysed the plankton food web structure for the middle section of the Danube (N-Hungary) based on weekly data across two consecutive hydrological years (2022–2023). Trophic interactions were collected from published literature, and functional traits were assigned to taxa where available. We aimed at simplifying the complex pelagic food web while preserving its essential functional components. Applying the "cheddar" modelling approach, an initial network comprised 105 plankton and microbial taxa connected by 293 trophic links, with a high number of diet gaps (759) indicated by the predation matrix. We minimised diet gaps to 170 through optimisation, and the resulting network still indicated a high degree of niche structuring. Trophic level analysis identified 92 unique trophic species with 262 interactions in the lumped food web, which therefore well-preserved functional complexity. Our preliminary results highlight the critical importance of how food web complexity is reduced. The remaining high number of unique functional roles in our case indicates minimal information loss, suggesting that the resolution of biodiversity remains detailed enough to detect links to ecosystem functioning. Further integrating diversity and dominance patterns may

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reveal whether network aggregation can preserve functionally unique rare or dominant components, helping to identify keystone food web components.

Keywords: *plankton food web, BEF, Danube River, network aggregation, trophic modelling*

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eDNA-Based Microdiversity Patterns Driving Pelagic Ecosystem Functioning in the Middle Section of the Danube River

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Abstract

Biodiversity enhances ecosystem functioning (BEF), a relationship widely studied in terrestrial and lake ecosystems, but it remains poorly resolved in river plankton, especially at fine taxonomic scales. Coarse taxonomic resolution may overlook micro-scale community patterns underpinning ecosystem functions. Using high-frequency eDNA monitoring (weekly, 2022–2023) in the middle Danube River (N-Budapest, Hungary), we investigated how plankton microdiversity shapes ecosystem functioning. We used 16S/18S rRNA gene amplicon sequencing to resolve bacterial and micro-eukaryotic community compositions at amplicon sequence variant (ASV) level. We first characterised temporal plankton dynamics across taxonomic scales (community- *vs.* ASV-levels); then assessed how environmental variables shaped these dynamics; and examined relationships between resource use efficiency (RUE, Chlorophyll-a relative to nutrient concentrations) and microdiversity. Our results suggest that broad community-level patterns hide substantial ASV-level turnover and compensatory dynamics, whereby declines in sensitive taxa are offset by resilient subpopulations. Fine-scale microdiversity supports ecosystem functions, e.g. in regulating resource use or trophic interactions, especially under short-term hydrological disturbances or long-term change. High-resolution microdiversity helps advance our understanding of riverine BEF and improves predictions of ecosystem responses to hydrological and climatic change.

Keywords: *eDNA, river plankton, ecosystem functioning, microdiversity*

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Zooplankton Diversity Patterns Driving Resource Use Efficiency at the Phytoplankton–Zooplankton Trophic Interface in the middle Danube River

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Abstract

Large rivers, such as the Danube River, are highly interconnected socio-ecological networks, where environmental constrains, including hydrological dynamics shape biodiversity. Despite the importance of biodiversity for ecosystem functioning (BEF), large river plankton communities mediating energy transfer remain insufficiently understood. Here, we quantified zooplankton resource use efficiency (RUE) as the ratio of zooplankton to phytoplankton biomass, and explored its relationship with taxonomic and functional diversity measures (richness and evenness) in a four-year high-frequency dataset from the middle Danube River (N-Budapest, Hungary). Our results reveal that Rotifera and the total zooplankton community differed in their biodiversity–function relationships. Systematic positive relationships only emerged between functional richness and RUE, whereas low evenness (high dominance) consistently predicted higher RUE only in Rotifera. Differences in BEF may reflect community organisation shaped by local environmental conditions and hydrological dynamics. By highlighting predictable links between large river zooplankton biodiversity and ecosystem functioning, our results contribute to a more mechanistic understanding of pelagic riverine processes and support ongoing efforts in basin-scale management and ecological assessment under increasing anthropogenic and climate-related pressures.

Keywords: *biodiversity, ecosystem functioning, fluvial ecosystem, evenness, functional diversity*

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Section 4

Climate change impacts

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From Tree Rings to Gauging Stations: A 250-year Perspective on Lower Danube Streamflow Variability and Its Large-Scale Drivers

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Abstract

Understanding long-term streamflow variability is essential for the sustainable management of the Danube River and its riparian ecosystems. We combine a 250-year tree-ring-based streamflow reconstruction from the Caraorman forest (Danube Delta, Romania) with observational hydroclimate analyses across the Danube River Basin to place recent changes into a multi-centennial context. The Quercus sp. chronology shows a stable and significant correlation with November–July streamflow at the Ceatal Izmail gauging station, allowing the identification of 14 extremely high (> 8,780 m^3/s) and 14 extremely low (< 5,300 m^3/s) flow years since ~1770. Pluvial years are linked to low-pressure systems over Europe and positive Atlantic SST anomalies favouring moisture advection from the Mediterranean and Black Sea, whereas dry years are driven by blocking highs and a northward shift of the storm tracks, with negative Atlantic and positive Baltic, North, and Mediterranean SST anomalies. Observations from eight gauging stations along the Danube (1958–2021) reveal basin-wide warming (0.1–0.6 °C/decade), rising potential evapotranspiration and climatic water deficit, a tendency towards aridification in the eastern basin, and a seasonal redistribution of runoff with decreasing April–September flows and increasing October–March flows. By bridging paleoclimate and instrumental records, this integrated approach provides a long-term baseline for risk assessment, riparian ecosystem conservation, and adaptive water management, supporting the socio-ecological sustainability of the Danube.

Keywords: *Danube River, streamflow reconstruction, tree-ring chronology, hydroclimate variability, atmospheric circulation*

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Flash Flood Monitoring in Vienna (Austria): Hydro-Geomorphic Effects and Environmental Change Scenario Modelling

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Abstract

From 12–20 September 2024 heavy rainfall events in Austria have caused severe flooding and associated on- and off-site impacts. Flash flood discharge values in Vienna's torrent systems were particularly extreme – some experiencing a 1,000-year event magnitude. It is evident that due to climate change heavy precipitation events have shown a clear increasing trend in recent decades, and that these events are highly likely to continue to increase in the future – in some cases with still unforeseeable consequences. The FlaMoVie (Flash Flood Monitoring in Vienna, 2024–2026) project is dedicated to 1. investigate causes, course, and potential consequences of flash flood events in Viennese torrent catchments, and to 2. assess associated hydrological and geomorphological effects combining monitoring and modelling approaches (including different environmental change scenarios). In this contribution, we will highlight some monitoring results derived from multi-temporal Terrestrial Laser Scanning, field mapping/measurements, and hydrometeorological gauge data of the Alsbach system, i.e. a ca. 2 km² large flash-flood-prone, densely forested, torrential tributary catchment of the Danube in the northwest of Vienna, Austria. Field data is further integrated in CAESAR-Lisflood landscape evolution modelling yielding high-resolution rates of erosion and sedimentation across the catchment, further allowing for future scenario modelling. The investigations at the Alsbach allow to deduce important and transferable knowledge on hydro-geomorphic response (scenarios) to torrential rainfall events in forested, small-scale headwaters in Viennese torrent catchments.

Keywords: *flash floods, water and sediment dynamics, geomorphic change, climate and land cover change*

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Scenario Modelling of Future Water Balance in a Transboundary Basin: Potential and Limitations from the Tisza Pilot Basin within the Danube Water Balance Project

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Abstract

The Danube Water Balance project aims to improve harmonised data management and to develop a joint water balance calculation methodology for the entire Danube River Basin. Here we demonstrate the advantages of the applied Community Water Model (CWatM) by presenting the model setup steps and results of a climate change scenario analysis for the Tisza River Basin (TRB), the largest tributary catchment of the Danube. Data availability posed a limitation for the study site. While global OA data on elevation, land use, soil, and meteorology were adequate, local information on water management was scattered. Calibration-validation resulted in acceptable performance for river discharge (validation KGE ranging from 0.18 to 0.88 with a median of 0.64). Gridded precipitation data from seven databases were used to check model sensitivity on the biases of meteorological forcing. Scenario analyses were performed with a two-fold focus: 1. a comprehensive climate impact assessment involving 11 climate models (ensemble) and three SSP pathways and 2. demonstration-oriented scenarios were simulated to verify the capabilities of the CWatM model to represent surface-subsurface water balance components under future climate and changing water demands. Simulations were evaluated with respect to changes in discharge characteristics as well as storage changes.

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Keywords: *hydrological modelling, Tisza River Basin, CWatM, water balance*

Acknowledgements: This work was supported as part of Danube Water Balance, an Interreg Danube Region Programme project co-funded by the European Union.

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Impact of High Air Temperature on Seasonal Mortality in the Danube Countries

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Abstract

The most evident feature of modern climate change is the increase in air temperature, which has numerous consequences, including adverse impacts on human health. Overall, the highest mortality rates in the Danube countries, such as Germany, Austria, Slovakia, Hungary, Romania, and Bulgaria, are observed during the cold season, whereas considerably lower mortality is recorded during the summer months. However, mortality may also increase during summer periods characterised by extremely high air temperatures.

In particular, such cases were observed during the 29th and 30th weeks of 2022, corresponding to the period from 18 July to 31 July 2022. During this period, the daytime maximum air temperature reached 35.6 °C in Vienna, 38.2 °C in Budapest, 39.1 °C in Zagreb, and 38.8 °C in Bucharest. The increase in weekly mortality compared with the period preceding the heat wave was as follows: Austria – 15.5%, Hungary – 17.4%, Croatia – 15.1%, and Romania – 17.3%.

Another prominent case of increased summer mortality occurred during the 29th week of 2024, from 15 July to 21 July 2024. The daytime maximum air temperature during this period and in the preceding days reached 34.9 °C in Vienna, 37.9 °C in Budapest, 36.4 °C in Zagreb, and 41.0 °C in Bucharest. In Austria, where the highest temperature was observed during the 28th week, mortality increased by 9.1% compared with the previous week. In other countries, the increase in mortality during the 29th week compared with the previous week was as follows: Hungary – 10.0%, Croatia – 15.7%, and Romania – 20.5%.

In the future, under conditions of continued air temperature increase and a growing proportion of the elderly population, a continuous rise in heat-related mortality during the summer period can be expected.

Keywords: *air temperature, mortality, Danube countries*

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Section 5

Integrated water management

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Cumulative Effects of Restoration Measures on the Ecological Conditions of the Upper Danube

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Abstract

Large river ecosystems, such as the Upper Danube, are highly fragmented due to extensive engineering measures for flood protection, hydropower production, and navigation. These modifications have led to the loss of instream habitat diversity, riparian habitats and floodplains, resulting in significant declines in aquatic biodiversity. Despite these challenges, large rivers continue to provide critical ecosystem services and support various human uses. Over the past 25 years, local-scale restoration measures have been implemented in the Upper Danube to improve the ecological conditions, particularly for fish populations and other organisms. This study applies the meta-ecosystem approach to assess the cumulative effects of these localised restoration efforts across a 150 km-long river network. The meta-ecosystem approach was applied to integrate local habitat conditions and spatial factors by utilising network metrics. By considering the impacts of historical alterations, with a focus on functional longitudinal and lateral habitat connectivity, we evaluated how restoration measures influence ecosystem functions, resilience, biodiversity, and ecosystem services. Results demonstrated how functional connectivity has decreased over the last 200 years, how restoration measures have improved connectivity over the last 25 years, how fish populations are distributed within the current river network, and the migration patterns exhibited by different species. This approach offers a comprehensive framework for better understanding and guiding future restoration strategies in highly modified river systems.

Keywords: *connectivity, river network analyses, meta-ecosystem, floodplain, fish, biodiversity*

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Hydrology-Driven Coupling of Semi-Aquatic and Terrestrial Ecosystem Engineers in Dynamic Floodplain Forests

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Abstract

Floodplain forests are dynamic interfaces of terrestrial and aquatic processes, yet the interactions between ecosystem engineers operating across these riparian boundaries are poorly understood. We aimed to test the hypothesis that different ecosystem engineers can facilitate each other, as beaver-induced tree mortality can favour woodpeckers in a complex ecotone system. Using structural equation modelling in a large, naturally functioning floodplain in Central Europe, we disentangled how water body characteristics, topography, forest composition, and beaver activity jointly structure woodpecker foraging and cavity excavation. We found that the habitat gradient from the secluded backwaters to the mainstream river promoted a higher abundance of native softwood trees, further increasing beaver activity. In turn, beavers improved woodpecker foraging and cavity excavation. The higher slope on the banks favoured invasive tree species, which reduced the activity of woodpeckers, but the steeper banks also continued to promote the presence of beavers. These findings provide the first empirical evidence of a cascading interaction between semiaquatic and terrestrial ecosystem engineers mediated by floodplain hydrology, topography, and forest structure. By maintaining and restoring

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natural hydrological processes in floodplain landscapes, we can amplify cross-boundary interactions of ecosystem engineers, thus helping to sustain native forest composition and biodiversity.

Keywords: *floodplain hydrology, ecosystem engineers, water body characteristics, forest structure, cascading interactions*

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LAREDAR – Lakes and Reservoirs in the Danube River Basin

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Abstract

LAREDAR (Lakes and Reservoirs in the Danube River Basin) is an international project funded by the Interreg Danube Region Programme (2025–2027). The project addresses one of the major challenges of water management in the Danube Basin: the improvement of coordinated operation and information exchange regarding lakes and reservoirs across national borders. As climate change increases the frequency and intensity of floods and droughts, effective transboundary cooperation has become essential for enhancing regional resilience.

The main objective of LAREDAR is to improve flood risk mitigation through the coordinated management of lakes and reservoirs. The project brings together experts, water authorities, research institutions, and stakeholders from several Danube countries to investigate how reservoirs can contribute to reducing flood peaks and supporting sustainable water management. Pilot studies in different regions of the basin provide valuable insights into the hydrological and operational impacts of reservoirs under various flood scenarios.

A key outcome of the project is the development of a GIS-based harmonisation platform that integrates data on lakes and reservoirs throughout the Danube River Basin. This platform supports data sharing, modelling, scenario analysis, and informed decision-making. In addition, LAREDAR will produce a transnational handbook containing operational guidelines, best practices, and recommendations for coordinated reservoir management.

By combining scientific research, digital innovation, and international cooperation, LAREDAR contributes to more effective, climate-resilient, and sustainable flood risk management across the Danube Region.

Keywords: *flood risk, drought, reservoirs, lakes, transboundary effect*

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Directives to Derive Micropollutant Emission Factors for Socially and Economically Heterogeneous Areas

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Abstract

Pathway oriented emission models are essential tools for assessing micropollutant loads transported by river systems. The models support water quality management by accounting for all diffuse and point sources that contribute significant inputs to the river load. Depending on the pollutant in question, municipal wastewater treatment plants (WWTPs) can represent (one of) the most substantial emissions. Since direct monitoring of each individual facility is economically and technically unfeasible, current practice estimates annual emissions as the product of emission factors (EF) – expressed as concentrations – and the discharged wastewater volume. However, deriving representative EFs is particularly challenging in large transboundary regions characterised by strong social and economic heterogeneity, such as the Danube River Basin (DRB), where wastewater infrastructure, treatment efficiency, and consumption patterns vary substantially.

This study presents a methodological framework addressing two major challenges: regional heterogeneity and censored measurement values, i.e. concentrations below the limit of quantification. The methodology combines permutational analysis of variance (PERMANOVA) with statistical reconstruction of censored datasets. During each permutation step, the distribution of censored values is estimated through regression on order statistics (ROS), based on fitting a lognormal distribution to the uncensored portion of the measurements. In addition to deriving representative EFs, the proposed method also provides uncertainty ranges. The methodology was applied to nine heavy metals (Cr, Ni, Cu, Zn, As, Ag, Cd, Hg, Pb) and four organic micropollutants: carbamazepine (CBZ), diclofenac (DCF), perfluorooctanoic acid (PFOA), and perfluorooctane sulfonate (PFOS). Four wastewater treatment development scenarios were evaluated: (sc0) the current

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state of municipal wastewater treatment; (sc1) implementation of the requirements of the 1991 EU Urban Waste Water Treatment Directive throughout the DRB; (sc2) introduction of quaternary treatment in WWTPs with design capacities above 150,000 population equivalent; and (sc3) implementation of quaternary treatment in WWTPs above 10,000 population equivalent.

The results demonstrate that identifying regional differences in WWTP influent concentrations constitutes the primary step in establishing representative EFs. For regions exhibiting statistical homogeneity, further differentiation according to treatment technology is required, followed – where sufficient data are available – by subdivision according to WWTP size. Using the derived EFs, current annual heavy metal emissions ranged from 54 kg/a for Cd to 125.000 kg/a for Zn. Organic micropollutant emissions were estimated to be 1,814, 7,478, 15.7, and 12.1 kg/a for CBZ, DCF, PFOA, and PFOS, respectively. Scenario analysis indicated that emissions may increase by 0–11% for heavy metals and 4–14% for organics under sc1 due to expanded wastewater collection and treatment coverage, while quaternary treatment implementation could reduce emissions by 0–50% in sc2 and by 26–74% in sc3. The proposed framework provides a statistically robust basis for deriving EF in highly heterogeneous regions and supports future policy-oriented emission modelling under evolving wastewater treatment regulations.

Keywords: *wastewater treatment, emission modelling, pathway-oriented modelling, scenario analysis, urban wastewater treatment directive*

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The Danube Restoration Hub: A Digital-Twin Decision-Support Environment for Wetland Reconstruction in the Danube Basin

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Abstract

Wetland reconstruction in the Danube Basin requires decisions that connect ecological priorities, hydrological dynamics, climate risks, local knowledge and long-term financing. The Danube Restoration Hub, developed within the Horizon Europe Restore4Life project, is a web-based platform designed to support this integration and to accelerate science-based restoration of riverine, floodplain and coastal wetlands. Our aim is to develop the Hub into a digital twin of the Danube Basin: a dynamic, continuously updated virtual representation of the wetlands of the basin that provides a strong, basin-scale decision-support environment for restoration. The Hub brings together Earth observation, in situ monitoring, hydrological and climate information, reference datasets and restoration case knowledge in a common interface. It links a data catalogue and geoportal with interactive reporting, reconstruction-project pages, statistical tools, citizen-science modules, learning resources, business and finance guidance, and an AI-supported assistant. Moving beyond static data integration, the digital twin assimilates these multi-source streams and couples them with process-based hydrological, ecological and climate models, enabling

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scenario simulation and forecasting. Users can explore restoration opportunities, test interventions, anticipate hydrological and climate responses, compare alternative futures before acting on the ground, document actions, access good-practice roadmaps, and communicate restoration benefits to policy makers, communities and investors. The platform is being developed as a practical boundary object between research infrastructures, restoration practitioners, public authorities and local communities. By combining FAIR data integration, digital-twin decision support and participatory communication, the Danube Restoration Hub contributes to the Restore4Life Wetland Reconstruction Accelerator and supports the EU Mission "Restore our Ocean and Waters" and wider implementation of the Nature Restoration Regulation.

Keywords: *wetland reconstruction, digital twin, decision-support system, Danube Basin, citizen science, Nature Restoration Regulation*

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Mixed section

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Dynamics and Trends of Dalmatian Pelican (Pelecanus crispus) Breeding Colonies in Bulgaria during 2016–2026

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Abstract

The Dalmatian Pelican *(Pelecanus crispus)* is a priority species for conservation in Europe and one of the emblematic birds of the Danube River. In Bulgaria, the species breeds mainly along the Lower Danube, where its population has historically been affected by wetland loss, fluctuating water levels and human disturbance. This study presents the dynamics and trends of Dalmatian Pelican breeding colonies in Bulgaria during 2016–2026. Monitoring was carried out at all breeding sites: Srebarna Lake, Persina Nature Park and Kalimok–Brushlen Protected Area, using regular field visits, fixed observation points, optical equipment, drone surveys and video surveillance systems. The results show a clear expansion of the breeding population. A new stable colony was established in Persina Nature Park in 2016, followed by another colony in Kalimok–Brushlen Protected Area in 2021. In 2025, a breeding attempt was also recorded in the Mandra-Poda Complex near Burgas, marking the return of the species to the southern Black Sea wetlands after several decades of absence. During the study period, the number of breeding pairs ranged from 55 pairs in 2022 to 171 pairs in 2026, the highest number recorded since systematic studies of the species in Bulgaria began in 1955. These results demonstrate the positive effect of targeted conservation actions, particularly the construction and maintenance of artificial nesting platforms, while also highlighting the need for long-term protection, monitoring and management of breeding sites.

Keywords: *Dalmatian Pelican, breeding colonies, artificial nesting platforms, population trend, conservation*

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Anthropogenic and Climatic Pressures on the Habitats of the Moustached Warbler (Acrocephalus melanopogon) in Central and Southern Europe

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Abstract

The Moustached warbler *(Acrocephalus melanopogon)* is a specialised, wetland-obligate passerine listed under Appendix I of the EU Birds Directive, serving as a vital bioindicator for the ecological stability of the Natura 2000 network. Due to its strict reliance on mature, semi-permanent reedbeds *(Phragmites australis)* standing in stable water columns, the species exhibits a heightened sensitivity to hydrological fluctuations and landscape alterations across its breeding range and migratory flyway.

This paper synthesises current data regarding the cumulative impacts of climate-induced environmental shifts and direct anthropogenic interference on the breeding of the species and wintering populations within the Palearctic-Mediterranean flyway.

On the breeding grounds, the intersection of escalating regional temperatures and extensive groundwater abstraction for agricultural and municipal use has significantly altered wetland hydrology. This localised desiccation accelerates terrestrial ecological succession, degrading exclusive nesting microhabitats and suppressing the aquatic macroinvertebrate biomass necessary for chick rearing. Concurrently, the species encounters a critical bottleneck on its wintering grounds in the Mediterranean basin. High site fidelity renders localised populations highly vulnerable to coastal development, infrastructure projects, and industrial encroachment, which eliminate crucial winter refugia. Our synthesis highlights that *A. melanopogon* is increasingly caught in a dual ecological squeeze: climate-driven hydrological instability and physical habitat eradication. Because the species possesses low ecological plasticity, maintaining the integrity of the Natura

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2000 network and wetlands under the Ramsar Convention requires stricter water management practices and the immediate legal protection of coastal Mediterranean wintering wetlands to prevent severe population fragmentation.

Keywords: *Acrocephalus melanopogon, hydrological changes, site fidelity, wetland conservation*

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The Significance of Meroplanktonic Life Style for Phytoplankton Growth and the Fate of Fine Suspended Particulates in Large Rivers

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Abstract

The existence and origin of true phytoplankton have been debated for a long time due to the inevitable flushing in rivers. Reynolds and Descy (1996) argued that self-sustaining phytoplankton must travel downstream more slowly than the advective speed. They proposed that algal growth in the dead zones (DZs) could support a persistent planktonic community downstream. However, an analysis of high-frequency data from three rivers revealed that flow-related dynamic changes in light prevented nearshore DZs from fulfilling this function in a sustained way. Conversely, rapid sedimentation and adaptation to low-light seem to be the backbone of an efficient strategy that avoids wash out through benthic retention at compromised growth rates due to low light availability – a typical strategy among diatoms. This suggests that true riverine phytoplankton growing in free-flowing sections should be meroplanktonic. Including the meroplanktonic life strategy in a simple river eutrophication model enabled us to describe the mean algal biomass profiles along the Danube and other rivers and revealed the importance of network topology for phytoplankton growth. Beyond algal growth, we propose that equivalent benthic retention mechanisms are relevant for the riverine transport and fate of fine particulate matter, including microplastics and hydrophobic micropollutants. With respect to the transformation dynamics of these substances, the resting time statistics of individual sediment particles are key characteristics.

Keywords: *meroplankton, benthic retention, fine particulates, fate of micropollutants*

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Spatial Variability of δ^2H, $\delta^{18}O$ and d-excess in Hungarian Groundwater: A 2020s Baseline for the National Atlas of Isotope Hydrology

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Abstract

The first systematic sampling campaign of subsurface water stable isotopes across Hungary was conducted between 2023 and 2026 with the support of several government bureaus. Groundwater samples were collected 2 to 4 times a year at approximately 350 locations. The stable hydrogen and oxygen isotope compositions of the samples were measured at the Institute for Geological and Geochemical Research. The isotope hydrological data along with the related geographical and hydrogeological metadata were compiled into a database. In regions of the country not covered by systematic monitoring, the gaps were partly filled with data from *ad hoc* sampling campaigns. The groundwater isotope hydrology database currently contains 760 δ^2H – $\delta^{18}O$ data pairs from 263 locations. The water samples represent a depth range from 1 to 440 m, but shallow groundwater (depth < 20 m) is highly overrepresented (n > 200). The ranges characterising the isotopic compositions span –107.2 to –42.2‰ for δ^2H and –14.8 to –4.3‰ for $\delta^{18}O$. The secondary isotopic parameter (dexc) ranges from –13.7 to 13.8‰. The database provides reference data not only for future but also to retrospective comparisons regarding either the mean values or the seasonality of groundwater in the early 2020s across Hungary. Data may also support paleoclimate studies, since groundwaters with the most negative δ values likely reflect recharge under colder climate conditions, during the Last Glacial Maximum. The data can be useful not only in Hungary but also for cross-boundary water bodies.

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The database is accompanied with a viewer and explorer website with a map-based interface https://izotopatlasz.elte.hu/index.html that helps visualise and empirically assess the underlying data via basic querying options both in spatial and temporal dimensions. The latest version of the database is available at https://hdl.handle.net/21.15109/CONCORDA/XRLKLY. A companion database is in the works for surface waters, which will be available through the same web interface in late 2026.

Keywords: *isotope database, groundwater, Hungary*

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From Early Warning to Water Diplomacy: Preventing Water Allocation Conflicts in the Danube Basin

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Abstract

Increasing climate variability, recurrent droughts and growing competition for limited freshwater resources are expected to intensify water allocation challenges across the Danube River Basin in the coming decades. The exceptionally warm summer of 2026, potentially amplified by ongoing El Niño-related climate anomalies, highlights the urgency of strengthening preventive governance before water scarcity evolves into social, economic or transboundary conflicts. While water allocation disputes are not inevitable, they become increasingly likely where competing demands from agriculture, public water supply, hydropower, navigation, tourism and ecosystem protection converge under prolonged hydrological stress.

This presentation examines practical approaches to preventing water allocation conflicts through early warning, stakeholder dialogue and water diplomacy. Using a forward-looking scenario set in the summer of 2032, it demonstrates how structured multistakeholder negotiation can simulate competing interests under severe drought conditions and serve as a practical tool for identifying governance challenges. The presentation discusses how evidence-based decision-making, facilitated dialogue and consensus-building can support balanced water allocation solutions and proactive drought management in the Danube Basin. It also presents a framework for developing policy recommendations that can contribute to a UNESCO Chair in Water Conflict Management Policy Brief, supporting regional cooperation, integrated water resources management and climate resilience. By translating scientific knowledge into practical governance

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approaches, the presentation contributes to strengthening the science–policy interface and fostering preventive water diplomacy before water allocation disputes escalate into broader regional crises.

Keywords: *water allocation conflicts, drought governance, water diplomacy, climate adaptation, Danube River Basin*

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Poster section

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Changes in Phytoplankton Functional Structure in Danube-Associated Lake Srebarna: Comparison of Historical and Recent Periods

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Abstract

Srebarna Lake, a UNESCO Biosphere Reserve and Danube-associated wetland ecosystem, is characterised by pronounced hydrological fluctuations and long-term environmental changes. This study assessed interannual changes in phytoplankton functional organisation in Srebarna Lake using the Reynolds/Padisák functional group approach. Two temporally separated periods representing historical and recent conditions were compared using datasets with similar coverage during the phytoplankton growing season. Relative biomass of functional groups was calculated for each sampling occasion and seasonally averaged to characterise the annual functional structure of phytoplankton assemblages. Functional richness was assessed based on the number of phytoplankton functional groups (FGs) and used as an indicator of the diversity of functional strategies. Marked shifts in dominant functional groups suggested substantial long-term reorganisation of phytoplankton assemblages over time. Lower seasonal functional richness was observed in recent years. Correlation analysis indicated water depth as a key driver of functional organisation and richness, highlighting the importance of hydrological conditions for phytoplankton dynamics. The FG-based approach proved effective for detecting long-term ecological changes in this hydrologically sensitive Danube floodplain lake.

Keywords: *phytoplankton, Srebarna Lake, functional groups*

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Linking Satellite-Derived Vegetation Cover to Microplastic Accumulation Patterns in Danube Delta Sediments

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Abstract

Microplastic pollution has emerged as a ubiquitous environmental issue in freshwater systems, yet the processes controlling its spatial distribution across heterogeneous aquatic environments remain poorly understood. We hypothesised that variations in satellite-derived vegetation cover are associated with differences in microplastic abundances and characteristics. This study investigates the relationship between vegetation cover and microplastic accumulation in contrasting aquatic systems from the Danube Delta. Vegetation cover was derived from multispectral satellite imagery using complementary spectral indices, enabling robust discrimination of vegetation density and water surfaces across sampling sites. Sediment samples were analysed for microplastic content, recording particle abundance, shape, size, and colour. Statistical analyses included Spearman's rank correlations to assess relationships between vegetation indices and microplastic metrics, non-parametric tests (Kruskal–Wallis and Mann–Whitney) to evaluate differences across vegetation classes and aquatic systems, and exploratory multivariate analysis to identify patterns in microplastic characteristics. Results indicate that sediments collected from areas with lower satellite-derived vegetation cover exhibit higher microplastic densities, suggesting an inverse relationship between vegetation cover and microplastic accumulation. These findings highlight the spatial variability of microplastic contamination in sediments in relation to vegetation cover, emphasising its relevance as an indicator of anthropogenically induced changes in aquatic environments.

Keywords: *microplastics, sediment contamination, vegetation cover, remote sensing, Danube Delta*

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Spatial Distribution of Potentially Toxic Elements in Surface Soils of the Moldova Nouă Mining Waste Dump, Romania

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Abstract

Mining waste deposits are persistent sources of potentially toxic elements in areas affected by former ore extraction and processing. This study evaluates surface soil contamination associated with the Moldova Nouă mining waste dump in Caraș-Severin County, Romania, with emphasis on spatial differences between the upper and lower sectors. Twelve surface soil samples were dried, homogenised, sieved to 250 µm, and analysed by energy-dispersive X-ray fluorescence spectrometry for Cr, Cu, Pb, Ni, Mo, Zn, Mn, and As. The highest concentrations occurred in the upper sector, reaching 5,617 mg/kg Cu, 1,080 mg/kg Mo, 991 mg/kg Pb, and 584 mg/kg As, indicating a strong influence of mining residues on soil geochemistry. Cr, Mn, and Ni were found at lower levels, suggesting a more limited association with the waste material.

Although most elements decreased downslope, Mo and As remained elevated in the lower sector, pointing to continued concern. Pearson correlation analysis indicated positive associations among Cu, Pb, Zn, Mo, and As, consistent with a common source related to copper ore processing. Principal Component Analysis separated samples from the upper and lower sectors, confirming differences in chemical composition and contamination intensity.

The results highlight substantial metal accumulation in surface soils and support the need for continued monitoring, mobility assessment, and ecotoxicological risk evaluation to guide future remediation and management actions.

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Keywords: *mining waste dump, potentially toxic elements, surface soils, Moldova Nouă, EDXRF*

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The SturNet Digital Mapping Tool for Environmental Monitoring and Sturgeon Conservation in the Danube–Black Sea Region

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Abstract

The conservation of sturgeons in the Danube–Black Sea system requires coordinated monitoring, data exchange, and tools linking scientific information with field observations and stakeholder involvement. In this context, the Interreg NEXT BSB00172-SturNet project has developed a digital platform to support environmental monitoring, communication, and decision-oriented visualisation for sturgeon conservation. This presentation focuses on the SturNet Digital Mapping Tool, a web-based interface for visualising spatial information related sturgeon habitats, sampling areas, monitoring stations, environmental conditions, and conservation layers. The tool integrates environmental parameters, habitat data, buoy locations, and eDNA-based information on sturgeon presence and associated biological indicators. Through interactive maps and selectable layers, it supports the interpretation of spatial data and communication among project partners, researchers, authorities, and stakeholders. The complementary mobile application is conceived as a field-reporting tool, enabling authorised users to submit georeferenced observations such as sturgeon sightings, bycatch, mortalities, pollution incidents, photographs, GPS coordinates, and automatic date and time records. By combining digital mapping with environmental and biological information, the SturNet platform provides a practical framework for improving data flows, supporting cooperation, and strengthening evidence-based sturgeon conservation across the Danube–Black Sea region.

Keywords: *Interreg BSB00172-SturNet, Digital Mapping Tool, mobile application, sturgeon conservation, Danube–Black Sea system*

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Integration of Time-Series Analysis, Satellite Data and Machine Learning in Water Balance Assessment for the Kis-Balaton Water Protection System

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Abstract

The Kis-Balaton Water Protection System (KBWPS), is a semi-constructed wetland established in the former Zala River estuary, which plays a key role in protecting the water quality of Lake Balaton. However, its water budget calculations remain uncertain due to difficulties in estimating evapotranspiration and correcting discharge measurements at the Zala-Fenékpuszta outlet from the KBWPS to Lake Balaton.

This research first applied Sentinel-2 imagery and NDVI-based vegetation classification to refine the spatial distribution of heterogeneous vegetation cover in the KBWPS. Eight vegetation classes were identified, enabling improved spatial estimation of evapotranspiration. Based on vegetation and meteorological data, an automated framework was developed to calculate evapotranspiration for any selected period (e.g. for 30 July 2024, the estimated daily evaporation was 13.4 mm day^{-1}).

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Second, a deep learning-based methodology was developed to correct discharge measurements at the Zala-Fenékpuszta outlet. Using different datasets (e.g. meteorological, hydrological, operational, water chemistry), a Long Short-Term Memory model was constructed in Python. Daily discharge, temperature, precipitation, and wind vector data were incorporated to derive seasonal correction coefficients. The developed methodologies provide a more accurate and automated framework for water balance calculations in the Kis-Balaton Water Protection System.

Keywords: *Kis-Balaton Water Protection System, water balance calculation, evapotranspiration, Sentinel-2, deep learning*

Acknowledgements: The research was supported by the National Multidisciplinary Laboratory for Climate Change, RRF-2.3.1–21-2022–00014 project.

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Molecular Approaches – from DNA Barcoding to DNA Metabarcoding for the Study of Aquatic Species in the Danube Delta – a Brief Presentation of the Project Results

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Abstract

The Danube Delta, one of Europe's largest wetlands, boasts rich aquatic life and biodiversity. Assessing this biodiversity can be challenging due to the complexities of the ecosystem and traditional sampling methods. An innovative solution is the use of environmental DNA (eDNA), which allows the detection of various species without direct capture. eDNA metabarcoding enables the identification of multiple taxa from a single water sample, often more efficiently than conventional methods.

While eDNA metabarcoding is increasingly being used to characterise aquatic biodiversity, its accuracy relies on the suitability of genetic markers and the completeness of reference sequence databases. The project "Molecular Approaches: from DNA barcoding to DNA metabarcoding for the study of aquatic species in the Danube Delta" involved analysing water samples to identify macroinvertebrates and vertebrates through eDNA

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metabarcoding. Tissue samples from fish and invertebrates were also analysed to enhance local databases with reference sequences. Results were compared with those from traditional sampling methods.

Keywords: *Danube Delta, environmental DNA, eDNA metabarcoding*

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Estimating Chlorophyll-a and Total Suspended Solids in the Danube River Using Sentinel-2 Imagery

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Abstract

This manuscript investigates the potential of Sentinel-2 satellite imagery for estimating Chlorophyll-a (Chl-a) and suspended sediment concentrations (SSC) in the Danube River. The methodology uses Level-1C Sentinel-2 imagery processed with the C2RCC processor to obtain atmospherically corrected reflectance data. Several approaches were evaluated, including automatically generated Chlorophyll-a and Total Suspended Matter (TSM) concentrations from the C2RCC processor, as well as various spectral indices. These were used to relate measured Chl-a and SSC values to satellite-derived reflectance and to develop regression models to estimate these concentrations when field measurements are unavailable. Model calibration was performed using in situ Chl-a and SSC observations. The main finding is that the proposed methodology demonstrates the applicability of satellite remote sensing to Chl-a and SSC estimation, although further research is needed to improve prediction accuracy across varying environmental conditions. The proposed methodology has the potential to support integrated water resource management by reducing the need for costly and time-consuming field sampling campaigns.

Keywords: *Danube River, Chlorophyll-a concentration, suspended sediment concentration, remote sensing, Sentinel-2*

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Aquatic Beetles of the Hungarian Danube: A Faunistic Overview with Special Reference to the Szigetköz, Gemenc and Béda-Karapancsa Floodplains

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Abstract

The Hungarian section of the Danube and its floodplain water bodies harbour a diverse aquatic beetle fauna, shaped by main-channel habitats, side arms, oxbows, marshes, canals and periodically flooded small waters. This presentation reviews aquatic Coleoptera records from the Hungarian Danube, focusing on the Szigetköz, Gemenc and Béda-Karapancsa floodplains. So far, 127 species have been reported from this river system, representing more than 40% of the Hungarian fauna. Twenty-seven species are known from the Danube main channel, including the five-decade-old records of *Nebrioporus canaliculatus* and *Dytiscus latissimus*. The three focal floodplains differ markedly in species composition. In the Szigetköz (70 species), the active floodplain fauna is dominated by rheophilic and widespread species, reflecting the homogenised water-supply system and strong hydrological modification, while protected-side water bodies add remarkable taxa such as *Hydroporus scalesianus* and *Hydrochus megaphallus*. By contrast, Gemenc supports the most distinctive assemblage (84 species), with several rare or floodplain-associated species, including *Graphoderus bilineatus, Rhantus exsoletus, R. consputus, Ilybius neglectus* and *Helophorus croaticus*. Béda-Karapancsa has a more generalist-dominated fauna (78 species) but includes noteworthy records of *Graphoderus bilineatus* and *Laccobius syriacus*. These patterns underline the conservation value of Danubian floodplain habitats and the need for continued faunistic surveys.

Keywords: *Coleoptera, floodplain wetlands, species composition*

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A Giant on the Brink: Genetic Insights into the Future of the Beluga Sturgeon (Huso huso)

Daniela Holostenco,[1] Ana Simionov,[1, 2] Elena Taflan,[1] Daniela Porea,[1, 3] Ana-Maria Drăgan,[1, 4] Adela Militaru,[1, 3] Marian Paraschiv,[1] Ștefan Honț,[1] Marian Iani,[1] Adrian Burada[1]

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Abstract

The Lower Danube River is supporting one of the last naturally spawning populations of the most critically endangered sturgeon species, the beluga sturgeon *(Huso huso)*. This study investigates the genetic status of a critically endangered sturgeon population from the Lower Danube using molecular markers and population genetic analyses. The results indicate that, despite a severe demographic decline, the population still retains an important component of its historical genetic diversity. Differences in genetic diversity among recruitment cohorts suggest temporal variation in reproductive success and in the contribution of spawning adults to natural recruitment. Population analyses revealed a generally weak genetic differentiation among cohorts, supporting the existence of a single population, while also highlighting fluctuations in recruitment dynamics. These findings indicate that the Lower Danube beluga sturgeon population remains genetically valuable but is characterised by unstable recruitment dynamics. The results provide important scientific support for conservation measures aimed at protecting spawning adults, preserving habitat connectivity, and monitoring natural recruitment.

Keywords: *Lower Danube, beluga sturgeon, critically endangered species, population structure, conservation management*

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Patterns of Floristic Change and Invasive Plant Expansion in the Srebarna Biosphere Reserve (Bulgaria)

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Abstract

The Srebarna Biosphere Reserve is one of the most valuable wetland ecosystems in Southeastern Europe and a key site for biodiversity conservation along the Lower Danube River. Owing to its unique hydrological conditions and habitat diversity, the reserve supports a rich flora comprising aquatic, marsh, riparian, and terrestrial plant communities. However, ongoing climate change and increasing anthropogenic pressure have led to substantial changes in vegetation structure and species composition, posing challenges to the conservation of this internationally important wetland.

The present study aims to assess recent changes in the flora of the Srebarna Biosphere Reserve and to evaluate the influence of climatic and anthropogenic factors on plant diversity and vegetation dynamics. The results indicate that fluctuations in water levels, prolonged drought periods, increasing temperatures, and changes in nutrient availability have significantly affected the composition and spatial distribution of aquatic and riparian vegetation.

A growing concern is the establishment and spread of invasive alien species, which threaten native biodiversity and ecosystem functioning, like Amorpha fruticosa, Acer negundo, Robinia pseudoacacia, Ailanthus altissima. Their expansion is facilitated by both environmental changes and human activities, resulting in modifications of plant community structure and a decline in floristic diversity. The observed trends highlight the sensitivity of wetland ecosystems to climate-related and anthropogenic disturbances and emphasise the importance of long-term monitoring programmes.

Keywords: *flora, wetlands, climate change, invasive alien species, Srebarna Biosphere Reserve*

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Microhabitat-Mediated Functional Homogenisation of Benthic Macroinvertebrates under Hydromorphological Change

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Abstract

Hydromorphological change alters microhabitat heterogeneity and stability, shifting substrates from coarse, diverse patches to finer, more homogeneous conditions. However, the biological implications remain poorly understood. We investigated how variation in microhabitat composition and diversity influences benthic macroinvertebrate communities in headwater streams subjected to different degrees of hydromorphological change. Microhabitats were quantified by relative coverage and heterogeneity was assessed using a diversity index. Macroinvertebrates were sampled using a multi-habitat approach. Community responses were assessed using taxonomic metrics, indicator value analysis, and size-related traits, including body length and biomass. Results showed that hydromorphological changes associate with shifts in microhabitat composition, reduced habitat heterogeneity and increased dominance of specific substrate types. Macroinvertebrate communities showed a parallel transition from diverse assemblages to those dominated by a narrower range of functional traits. Sites with lower microhabitat diversity had a higher prevalence of smaller-bodied organisms and reduced variability in size-related traits. These findings indicate that microhabitats act as ecological filters linking hydromorphological change to biological responses. The shift toward functional homogenisation highlights the importance of maintaining microhabitat diversity to sustain ecosystem functioning and resilience in headwater streams.

Keywords: *hydromorphological change, microhabitat heterogeneity, macroinvertebrate communities, streams*

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Sea Water Level Rise Induced by the Impact of Climate Change on Fresh, Brackish and Salt Water Fish Species, Communities, and Associations of Danube, Rhône and Dniester Deltas

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Abstract

Currently under progress, a European joint continental project examines 17 major deltas (Volga, Danube, Pechora, Northern Dvina, Neva, Rhine-Meuse-Scheldt, Rhône, Dnieper, Dniester, Po, Vistula, Don, Western Dvina, Vjosa, Mezen, Loire, Seine, Elbe and Glomma) regarding the sea water level rise phenomena induced by the impact of climate change on fresh water, brackish water and salt water ichthyofauna. The first obtained results have concerned the Danube, Rhône and Dniester deltas, results which are highlighted in our presentation.

The Danube, Rhône and Dniester deltas are critical global biodiversity hotspots that serve as essential shelters, nurseries, and transitional areas for river, wetlands, and marine ichthyofauna. Climate change-induced sea level rise represents a major, historical, and

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ongoing stress factor for these dynamic deltaic ecosystems, threatening their habitats, biocoenoses and biodiversity, including fish species, associations and communities.

On average, for all three studied deltas, Danube, Rhône and Dniester, one in four fish species follow a trend of facing and will face severe impacts, one in four face and will face average impacts, one in four face and will face low impact, and one in four remain and will remain unaffected.

At the same time there are variations from one delta to another, related to different natural and anthropogenic regional environmental conditions and have diverse impact on different fish species.

All the studied fish species are and will be selectively affected based on their bioecological features, while others have adapted and will adapt to sea level rise phenomena induced by climate changes.

Crucially, across all three deltas studied, the shifts in the structures of fish communities are projected to trigger ecological feedback loops. Rather than acting only as passive victims, the affected fish populations will actively stimulate further environmental transformations, driving cascading changes throughout the diverse matrix of interconnected riverine, deltaic, and marine neighbouring ecosystems. Consequently, implementable, in situ-adapted management strategies are urgently required to mitigate these risks and preserve regional fish diversity and bioecological health status.

Keywords: *climate change, sea level rise impact, Danube Delta, Rhône Delta, Dniester Delta, fish*

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Numerical Analysis of Water Infiltration through Canals in Semi-Arid Regions

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Abstract

In the upper part of the subsurface area (~0.5–1 km depth), the groundwater (GW) flow systems are controlled by the topography, to be more precise, the shape of the (ground) water table. However, the combination of natural and artificial processes can significantly alter the groundwater table and simplify its hierarchy, leading to changes in GW flow patterns and thereby causing irreversible, long-term damage to agriculture, ecosystems and drinking water management. In Hungary, the Danube–Tisza Interfluve (DTI) is one of the regions suffering from drought. The application of surface water retention techniques (e.g. water infiltration through abandoned canals) can help mitigate environmental damage. But how effective is this method?

Numerical modelling was carried out to investigate the effectiveness of a canal-based water retention measure. The time-dependent simulations were set up in synthetic models in which the following parameters were varied: 1. the depth of the water table, 2. the water level in canals, 3. the hydraulic conductivity of the near-surface porous media, and 4. the shape of the water table. As a result of the comprehensive parameter test, we found a "critical distance" beyond which the (extra) water infiltration no longer raises the water table. Of course, this "critical distance" varies across space and time, depending on

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model parameters; hydraulic equilibrium was established in all simulations. For example, after 20 years, the additional hydraulic effect extends up to a maximum of 200 m from an individual canal.

Keywords: *natural water retention measures (NWRM), groundwater flow simulation, climate change, drought damages*

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Bioindication of Pollution and Water Quality Along Sturgeon Migration Routes in the Ukrainian Section of the Danube Delta

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Abstract

Danube sturgeons are among the most vulnerable fish species due to the high sensitivity of their migration routes and feeding habitats to hydromorphological alterations, benthic habitat degradation, and water pollution. Bioindication based on macroinvertebrate community structure is one of the principal approaches for assessing water quality of these habitats, which constituted the main objective of this study. The investigations were conducted during the summer and autumn periods from 2023 to 2025 within the Danube Delta, from the Solomoniv Branch (near Liski village) to the Bystryi Branch.

The values of the Zelinka–Marvan saprobic index at most sites did not exceed the limits of the β-mesosaprobic zone. Increased organic pollution was consistently observed near the town of Vylkove throughout the entire study period. According to the BMWP index, water quality predominantly corresponded to Classes II–III (fairly clean to moderately polluted waters), while the BBI indicated Class II water quality (fairly clean waters). However, in water areas adjacent to settlements (Liski village and the town of Vylkove), water quality occasionally declined to Class IV (polluted waters) according to the BMWP and to Class III (moderately polluted waters) according to the BBI.

Thus, the water areas constituting sturgeon migration routes in the Danube Delta are generally characterised by a low level of pollution. Nevertheless, a deterioration in these indicators has been observed in recent years within populated areas, which may negatively affect sturgeon populations, particularly within their feeding habitats.

Keywords: *Danube Delta, sturgeon migration routes, bioindication, macroinvertebrate community, saprobity, water quality*

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Late Holocene Evolution of the Razelm–Sinoe Lagoon System (Danube Delta): A Multi-Proxy Reconstruction of Coastal Environmental Change

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Abstract

Long-term records of coastal environmental change provide an essential baseline for understanding the impacts of ongoing climate change on deltaic systems. The Razelm–Sinoe Lagoon System, located along the southern margin of the Danube Delta, preserves a valuable archive of environmental variability in the northwestern Black Sea over the last ~3,000 years. In this study, a multi-proxy approach integrating sedimentological, geochemical, and micropaleontological (ostracod) analyses was used to reconstruct the Late Holocene evolution of this complex transitional environment. Five distinct paleoenvironmental phases were identified, documenting the transition from fluvially dominated settings to increasingly restricted lagoonal conditions, interrupted by episodic marine incursions and periods of pronounced salinity variability. The development of successive Danube Delta lobes, particularly the Dunavăț lobe (~2.6 ka BP), strongly influenced sediment supply, hydrological connectivity, and lagoon morphology. Abrupt paleosalinity shifts recorded by ostracod assemblages indicate recurrent episodes of enhanced storm activity, which likely caused barrier breaching and short-lived marine inflows, particularly around 1.4–1.5, 1.2–1.3, 0.9–1.0, and 0.6–0.7 ka BP. These findings demonstrate the long-term sensitivity of the Razelm–Sinoe Lagoon System to changes in hydrological regime, sediment dynamics, and extreme coastal events. By providing a millennial-scale perspective on the natural variability of this coastal ecosystem, the study offers an important baseline for assessing the impacts of ongoing climate change and improving future adaptation and management strategies for the Danube Delta.

Keywords: *ostracods, multi-proxy analysis, paleosalinity, paleostorms, Black Sea*

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