ISSN 2070-1292

danube news

International Association for Danube Research (IAD)

Danube oxbow in the Viennese nationalpark Lobau (Photo: Stefan Preiner)

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No. 48

WEPASS Project - Making the Iron Gate Dams passable for migratory fish

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DOI: 10.5281/zenodo.10257946

Abstract

European rivers are obstructed by more than one million barriers that have resulted in excessive loss of river continuity (Belletti et al. 2020). On the main course of the Danube River there are 83 longitudinal continuity interruptions, out of which 65 dams are used for hydropower (ICPDR 2022a). The Iron Gate Hydropower and Navigation System is one of the largest river engineering projects undertaken in Europe, with the dams mainly built to provide hydropower and flood protection, and to facilitate navigation along the Danube. These infrastructures introduced barriers to fish migration. Hence, ensuring passage opportunities for fish at the Iron Gate dams is considered to be of major importance for the conservation of migratory fish populations in the Danube River basin. Restoration of river continuity at these sites would reopen an additional 900 km for migration up to the Gabčikovo dam, providing suitable habitats and spawning grounds along the Danube and its tributaries. Knowledge about fish behavior and movements in the vicinity of these river infrastructures is required to build effective up- and downstream passage facilities to allow the migration of fish species. To gain insight in the approach routes and aggregation areas a refined approach to acoustic telemetry is employed to support migration facilitation.

Introduction

The Danube River is the second longest river in Europe (2,860 km) after the Volga. It crosses ten countries and has an average multi-annual flow of 6,500 m^3/s before it reaches its delta and dewaters into the Black Sea (Hont et al. 2022). The Danube River is a biodiversity hotspot in Europe, inhabiting 2,000 plant and 5,000 animal species, including highly endangered sturgeon species.

The Iron Gate dams (IG I - rkm 943 and IG II - rkm 863) represent the first two impassable obstacles for fish migration along the Danube River from the Black Sea *(fig. 1)*. The construction of the IG I was completed in 1972 and IG II in 1984. The border between Romania and Serbia follows the

Figure 1. *Iron Gate I (rkm 943) on the left and Iron Gate II (rkm 863) on the right (Photo: Smederevac-Lalić)*

Danube in this area, and the two countries share the dams *(fig. 2)*. The Iron Gate system has transboundary effects; IG I created a reservoir of about 3.2 billion m³ and 270 km total length (up to Novi Sad, Serbia), trapping 20 million tons of sediment per year (Comoglio 2011).

The IG I dam has a total width of 1,278 m with symmetrical design. Both countries have an equal exploitation of the water for electricity production and navigation. The maximum design head and the range of water level variation both up- and downstream of the dam are important information for designing fish passes. At IG I dam the maximum design head amounts to 29.10 m; the water level fluctuations (fish pass operation ranges) are in total 4.45 m upstream and 2.0 m downstream.

The IG II is a system of two dams which exploits the ramification of the Danube River in two branches *(fig. 1, 2)*. The upper dam is located on the Romanian side, on the Gogoșu branch at rkm 875, with a total width of 509 m. The lower IG II dam is located on the main branch of the Danube River between Serbia and Romania, at km 863 with a total width of 1,009 m. The fish pass design head is 11.75 m and the operation results in water level fluctuations of 1.25 m upstream and 5.78 m downstream the dam.

The restoration of river continuity at the Iron Gate dams, being the 'doorway' to the middle and upper Danube River basin, has been classified as of 'utmost priority' in the Danube River Basin Management Plan Update 2021 (ICPDR 2022a). In 2022, Danube Ministers welcomed the progress made in the assessment of possibilities for opening fish migration routes at the Iron Gate dams and emphasized the need for ensuring the necessary financial resources for the implementation of technically and economically feasible solutions (ICPDR 2022c). Due to their substantial size and complexity, restoring fish passage at the Iron Gate dams is extremely challenging. There is no ready-to-use solution for fish passage facilitation considering the scale of the river, the size of the target species (sturgeons up to 7 m long), the dimensions of the dam structures and their morphological environments and the location on the border between two countries, and the hydropower and navigation utilization.

Fish migration routes can be re-established by building fish passages

The construction of dams has blocked upstream fish migration, impaired downstream passage survival and decreased available spawning, nursery, wintering, and feeding habitats (Lenhardt & Pekarik 2021). Additionally, the modification of riverbeds for navigation purposes caused negative impact on migratory species. The most famous fishes of the Danube, also recognised as flagship species by the International Commission for the Protection of the Danube River (ICPDR), are the sturgeons, which spawn in the river and spend the majority of their lives in the Black Sea. Sturgeons are among the most ancient fish families in the world, with some 80% of the sturgeon species globally being endangered to become extinct (IUCN 2022). Before the construction of the Iron Gate dams, sturgeon migrated from the Black Sea as far upstream to Austria and Germany. The sturgeons in the Danube today are restricted in their migration to the Iron Gate II dam from the Black Sea (Paraschiv et al. 2021). Only one potamodromous (riverine) sturgeon species, the sterlet *(Acipenser ruthenus)*, is still common in the Middle and Upper Danube. Consequently, sturgeons are among the priority species for recovery measures, including the construction of fish passages. In addition to the sturgeons, there are numerous other migratory fishes that need to migrate up and down the

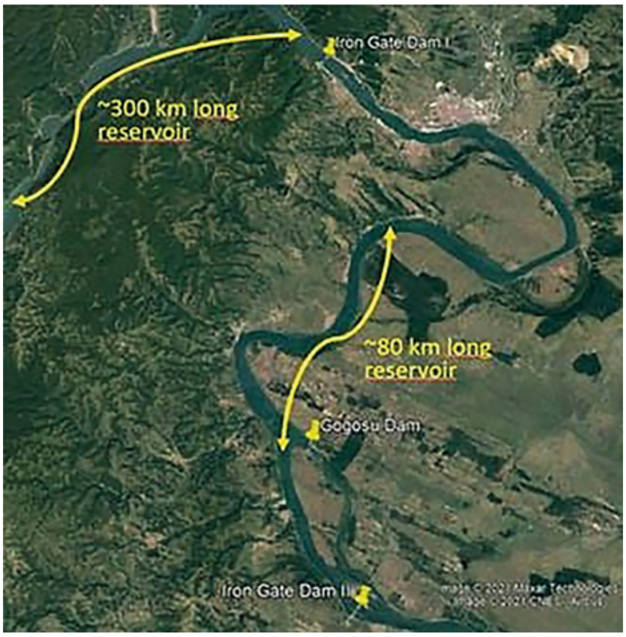

Figure 2. *Study area, Iron Gate I and II and Gogoşu dams (Photo: Google Earth)*

Figure 3. *The St. Ours dam on the Richelieu River in Canada has one of the few proven efficient fishways for (lake) sturgeon (Thiem 2013)*

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Figure 4. First acoustic telemetry project 'Fish behaviour preparatory study at Iron Gate dams and reservoirs' (DDNI 2015)

Danube in order to fulfill their life cycles, such as common nase *(Chondrostoma nasus)*, barbel *(Barbus barbus)*, vimba bream *(Vimba vimba)*, asp *(Leuciscus aspius)*, Pontic shad *(Alosa immaculata)*, European eel *(Anguilla anguilla)* and other species.

A fish passage facility represents a structure that allows fish to pass over or around an obstacle. Worldwide, most of the fish passages were created for salmonids (strong swimming capabilities), and clupeids (generally pelagic). In contrast, sturgeons are bottom-oriented species with a lower swimming performance compared to salmonids (McElroy et al. 2012; Lenhardt 2021). Since the approach of sturgeons towards a barrier depends upon the morphology and hydrology of the river, detailed information must be available to ensure proper location of the entrances for fish passage facilities. The design of successful fish passage facilities for sturgeon for upstream and downstream migration is still in an experimental phase. There are some lessons learned *(fig. 3)* and particular success in this topic provides hope for reconnecting fragmented sturgeon populations (Lenhardt 2021).

In the past there have been some preparatory activities to make the Iron Gate dams passable for migratory fish species. The first assessment (FAO scoping mission) of possibilities to restore fish migration in the Danube River, following the legal requirements of the EU Water Framework Directive, was conducted in 2011 (Comoglio 2011).

Following the FAO mission, under a Dutch-Romanian partnership together with the ICPDR, the project 'Towards a Healthy Danube - Fish Migration Iron Gate I and II' was completed in 2014. The project report outlined possible technical solutions and provided a road map for further project implementation (de Bruijne et al. 2014).

Between 2014 and 2015 the European Investment Bank funded preliminary fish telemetry investigations down-

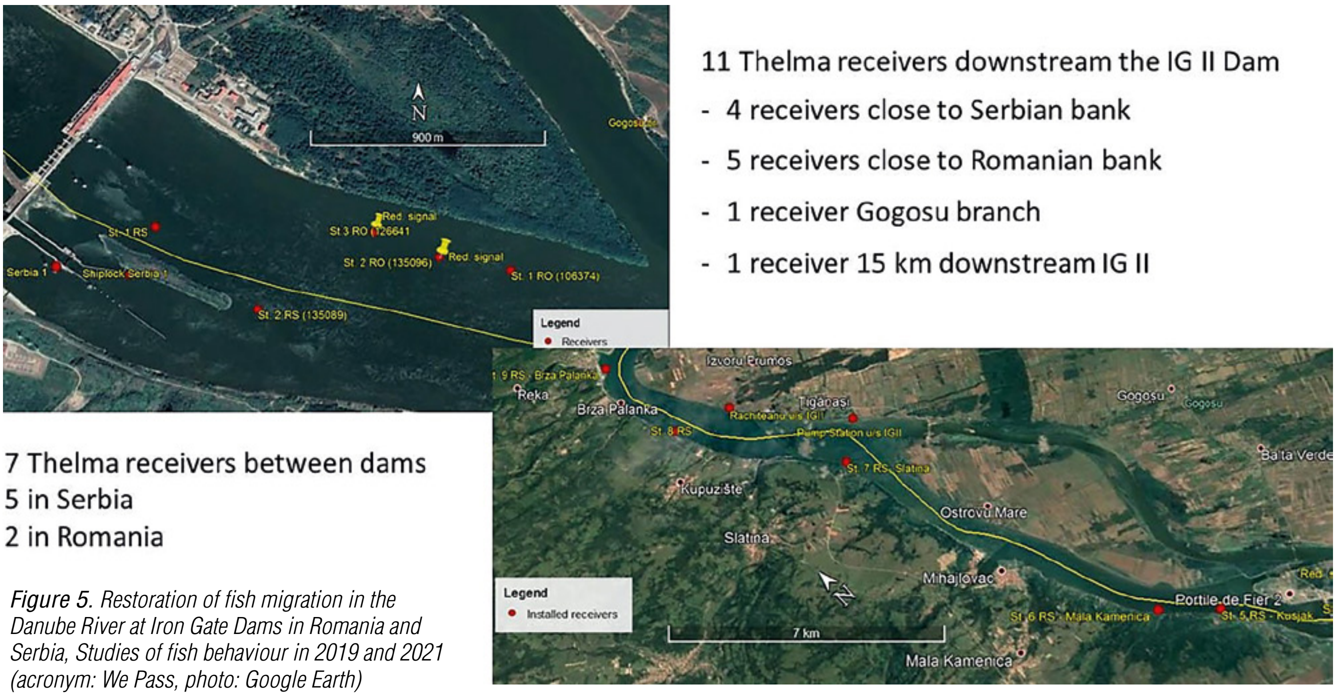
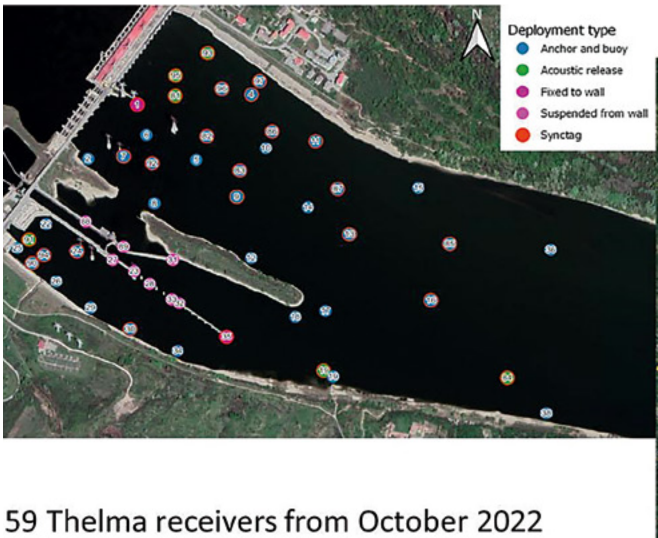


Figure 5. Restoration of fish migration in the Danube River at Iron Gate Dams in Romania and Serbia, Studies of fish behaviour in 2019 and 2021 (acronym: We Pass, photo: Google Earth)



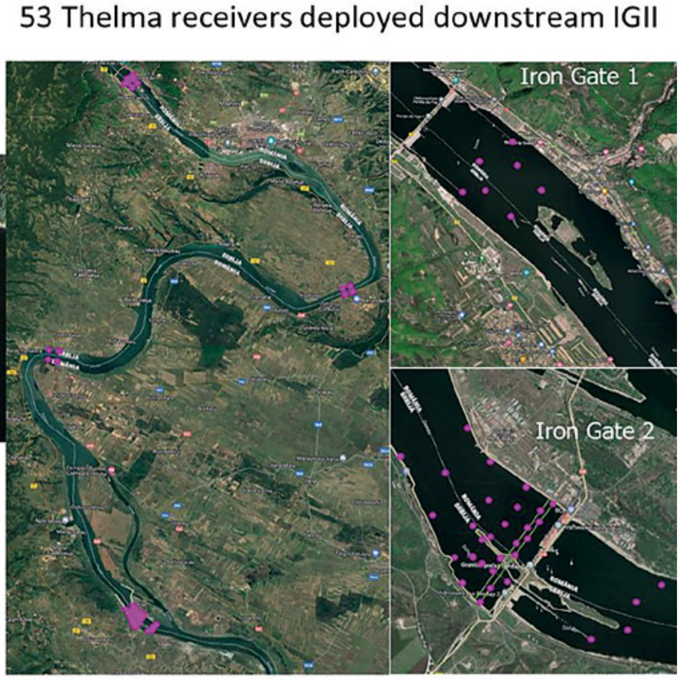


Figure 6. Receiver arrays in the WePass 2 project (left – 53 receivers deployed downstream IG II in October 2021, right – arrangement as from October 2022, downstream of IG I, between the dams and downstream IG II, photo: Google Earth).

stream of IG II (Suciu et al. 2016; Lenhardt et al. 2021). As a continuation of the biological fish investigations, telemetry methods and equipment were used to work on the strategy for monitoring sturgeon behaviour/movements to ensure the function of future up- and downstream fishways *(fig. 4).*

The project named 'WePass' between 2018 and 2021 was funded by the European Commission (DG REGIO) (ICPDR 2022b). The objectives of the project were an analysis of the current situation and technical data gathering (Milovanović et al. 2021), a literature study on sturgeon behaviour and passage (Lenhardt 2021), fish movement monitoring using 2D hydroacoustic telemetry (Paraschiv et al. 2021), and preparatory engineering design works such as the development of a technical 3D model of the dams (CDM Smith 2021, *fig. 5)*.

In March 2021, the European Commission (DG ENV) commissioned the 'Pilot Project: Making the Iron Gate Dams passable for Danube Sturgeon' (acronym WePass2) to conduct a feasibility study analysing the options to establish fish migration at the Iron Gate that includes (a) the study of alternatives for up- and downstream fish passage restoration at both Iron Gate dams, (b) a preliminary design of fish passes comprising all their technical elements, and (c) a cost estimate for the construction of the fish passes. The WePass2 project is still ongoing and will be finalised in September 2024 (CDM Smith 2023). The activities include substantial fish movement investigations using 3D acoustic telemetry *(fig. 6)*.

Each of the aforementioned projects made a new contribution and a step further in order to find best solutions for making the Iron Gate dams passable for fish. In an international workshop in the WePass project experts including scientists and engineers agreed that fish passes are technically feasible at the Iron Gate dams. Yet, the site-specific application of appropriate solutions need to be assessed and their feasibility proven as one of the WePass2 objectives.

Monitoring of migratory fish in the Iron Gate area

Acoustic telemetry was used to track fish movements and migrations *(fig 7. left)*. The studies were performed by tagging fish with acoustic transmitters and releasing them downstream and upstream of IG II. The fish were tagged with a transmitter implanted into the body cavity *(fig. 8)*. The movements of tagged fish were recorded by receivers (hydrophones), deployed in preselected places in the river, when they were within the detection range of the receivers *(fig. 7 right)*. Receivers record the ID of the individual tag (fish), the time when the signal is recorded and swimming depth of the tagged fish. The movements of tagged fish were recorded by a combination of automatic tracking of fish passing receivers deployed in the river and by manual tracking from a boat.

Working in a large river is challenging due to the variable environmental conditions. Studies of detailed behaviour of tagged fish can only be fine-scaled with an appropriate receiver deployment. Designing the array with a higher number of receivers then allows estimating tracks of tagged fish even if individual receivers are lost. Based on the experience from the WePass project in which a limited number of acoustic receivers was used, in WePass2, cutting-edge technology was applied allowing fish movement to be recorded in three

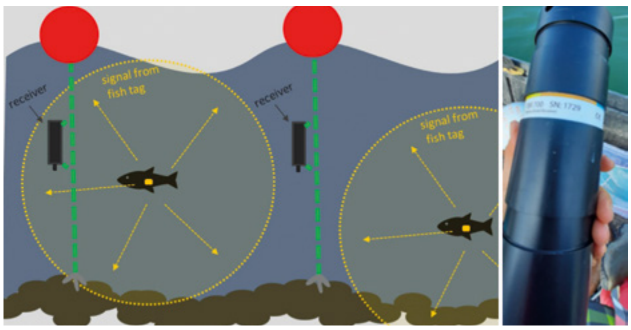


Figure 7. Illustration of two receivers that receive signals from tagged fish – left (Paraschiv et al. 2021), receiver ThelmaBiotel – right.

Figure 8. Tagging of fish was carried out by specially trained staff from the Romanian (DDNI) and Serbian (UB-IMSI) team members.

dimensions with more receivers deployed in the investigation area (*fig. 6*, CDM Smith 2022).

Studies of fish movement in 2019 and 2021

A total of 185 fish were tagged; 61 in autumn 2019 and 124 in spring 2021 (Smederevac-Lalić et al. 2023). Vimba bream, common nase, barbel and asp are known to be migratory species, which can perform long-distance movements. This was confirmed in our study, with many tagged individuals performing extensive movements, both below the IG II dam, in the Gogosu branch and in the reservoir. Several barbel, common nase and vimba bream moved upstream through the entire IG II reservoir to IG I, which is located 76 km from the release site in the reservoir. Barbel and vimba bream were the two species showing the most extensive movements. The study also confirmed that there is large individual variation in movement strategies and behaviour within these species.

Results helped identifying potential areas for fish passes downstream of IG II and in the Gogoşu branch, proved fish movements in/through the reservoir between IG I and II, as well as distribution of fish downstream of IG I (Paraschiv et al. 2021).

No fish released downstream of IG II were detected in the IG II reservoir, which highlights that the two ship locks do not represent viable routes for upstream migration past IG II (Paraschiv et al. 2021). There was also no clear pattern on which side of the river tagged fish preferred to move along.

Fish movement studies in 2022 and 2023

The correct location and functionality of a fish pass entrance (i.e., attraction) are key factors for fish pass efficiency. Even the best designed fish passes will not function if the fish cannot locate the entrance(s) or are not motivated to enter. This was the reason for further monitoring of migratory fish move-

Figure 9. Deployment of the receivers and range testing.

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ment in the WePass2 project by increasing the hydrophone deployments at IG I and II, and in the IG II reservoir (*fig. 6*). 3D fish telemetry is being used to investigate the movement and distribution of fish downstream of IG II (2021 - 2022) and in the IG II reservoir (2022 - 2023). The results of the investigations are being used to (a) identify the best areas to place fish pass entrances that must work for the design flow/water level regimes during the migration periods and (b) to determine appropriate concepts and/or strategies for downstream fish passage including technical facilities and their locations. A new mathematical approach is being applied to estimate highly precise tracks of tagged migratory fish (ca. 1 m accuracy) (Baktoft et al. 2017).

Fieldwork started in October 2021 with a survey of the areas for receiver deployment, range testing and receiver array installation. Expert biologists from Romania, Serbia, Denmark and Norway worked together (*fig. 9*), building on their experience gained in WePass in organizing and setting up the necessary telemetry infrastructure including catching and tagging migratory fish. In the first stage, 53 receivers were deployed downstream of IG II in October 2021. Additional receivers were added in spring 2022 to augment the array and improve tracking precision. In October 2022, the majority of the hydrophones were transferred and placed in the IG II reservoir. The latest receiver array has improved the accuracy of the tracks of tagged fish swimming between IG I and IG II (upriver and downriver movements) and security of data collection (*fig. 6*).

From October 2021 until November 2023 a total of 202 fish were tagged: sterlets, asps, barbels, vimbas, common nase, eel. From October 2022, with the new improved receiver array between IG I and II, all tagged fish were released in the IG II reservoir. Results of our detailed fish movement investigations showed that tagged and released fish in the reservoir can and will migrate up to IG I and back downstream to IG II.

Focusing on Iron Gate II, different migratory fish species used different areas downstream of IG II dam to aggregate. Based on the fish tracks, aggregation areas were identified. Figure 10 illustrates movement of 2 tagged fish (sterlet and vimba bream) under the IG II in 24 hours.

Applying the results of our fish movement analysis and 2D hydro-numerical modelling, various different upstream fish passage options were developed and their optimal locations were identified. Since an effective fish pass should work for all migratory species, multi-species passes are considered. The options include permanent structures (e.g., pool-type and nature-like fish passes, fish locks and fish lifts), operational changes (e.g., to the ship lock operation) and interim solutions (e.g., so-called trap & barge).

Restoring fish migration can only be effective if safe downstream passage is provided, too. Therefore, an assessment of the downstream passageways of fish and turbine survival was conducted and options for downstream fish passage (i.e., different fish protection technologies and alternative

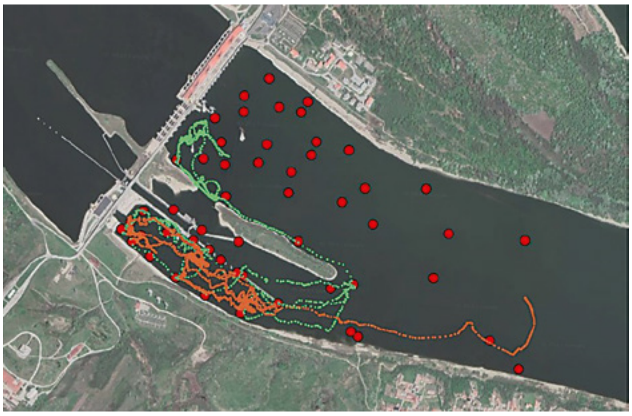

Figure 10. Movement of one sterlet (orange line) and one vimba bream (green line) in the area under Iron Gate II dam. Red dots are location of acoustic receivers.

hydropower management approaches) were identified. Using the outcomes of the recent fish movement investigations in the IG II reservoir, suitable fish protection and downstream passage possibilities will be detailed further.

The up- and downstream passage investigations and options were presented at a stakeholder meeting in May 2023 to the EU Commission, representatives of both dam owners/operators and international experts.

Conclusion

The status of migratory fish is a parameter of the ecological condition and key indicator of the habitat quality of the entire Danube River Basin. The Danube River connects all tributaries in the basin for migration. Since the Iron Gate dams represent significant migration barriers for fish, migratory fish, such as sturgeons as flagship species but also shad, nase or barbel are particularly affected, since they are prevented from moving up- or downstream between their historic spawning grounds and their feeding and wintering habitats. The implementation of measures enabling sturgeon migration across the Iron Gate dams would make large areas of the Danube River Basin accessible for the migration of the Danube fish species again and would reinstate the river continuum. As such it will contribute significantly to the recovery of the Danube sturgeon populations and long/medium distance migrating fish species as well as reverse the genetic drainage that is caused by the outmigration of the fish below the dams.

At the same time, legal obligations according to relevant EU legislation – such as the EU Water Framework Directive with its objective to achieve good (ecological) status of all waters in Europe and the EU Habitats Directive aiming to ensure that species and habitat types are maintained, or restored, to a favourable conservation status – are met by contributing to EU environmental objectives including the sustainable use of protection of water and marine resources, as well as the protection and restoration of biodiversity and ecosystems. The Danube countries have a strong commitment to bring the Danube River back to a better ecological status and to establish and preserve self-sustaining fish populations, which includes the restoration of the longitudinal connectivity of the river necessary for fish.

The location and site-specific design of the entrance(s) to any fishway are crucial features of their functionality. Therefore, information on the movement and (horizontal and vertical) distribution of fish trying to pass the dams is a prerequisite to ensure that the fishway entrance(s) will be located in an area where it/they can be detected by as many up- or downstream moving fish as possible. Sturgeon conservation activities including passage facilitation to Iron Gate dams and further upstream, are prominently addressed in the Danube River Basin Management Plan Update 2021 of the ICPDR, endorsed by Danube Ministers in February 2022.

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Climate change in the Danube Delta and its consequences

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DOI: 10.5281/zenodo.10257974

Abstract

Climate change in the Danube Delta, as well as changes in water temperature, evaporation from the water surface and the ecological state of wetlands have been identified on the basis of available observational data and satellite images. It was determined that during the last six decades, the air temperature in the Danube Delta has increased significantly, by more than 2 °C. Simultaneously, the precipitation slightly decreased. As a result, the climate in the studied region became drier than it was at the beginning of the observation in the 1960s. According to the air temperature increase is observing the water temperature increase and the increase of the evaporation from the water surface. It is important, that dependence between evaporation and water temperature is nonlinear. This means that even a small increase of the water temperature causes an essential increase in evaporation. In turn, such changes concern the Danube wetland. During the last years, several fires were observed, which comprised a large area. At the same time, some shallow lakes fell dry and were transformed into salt marshes.

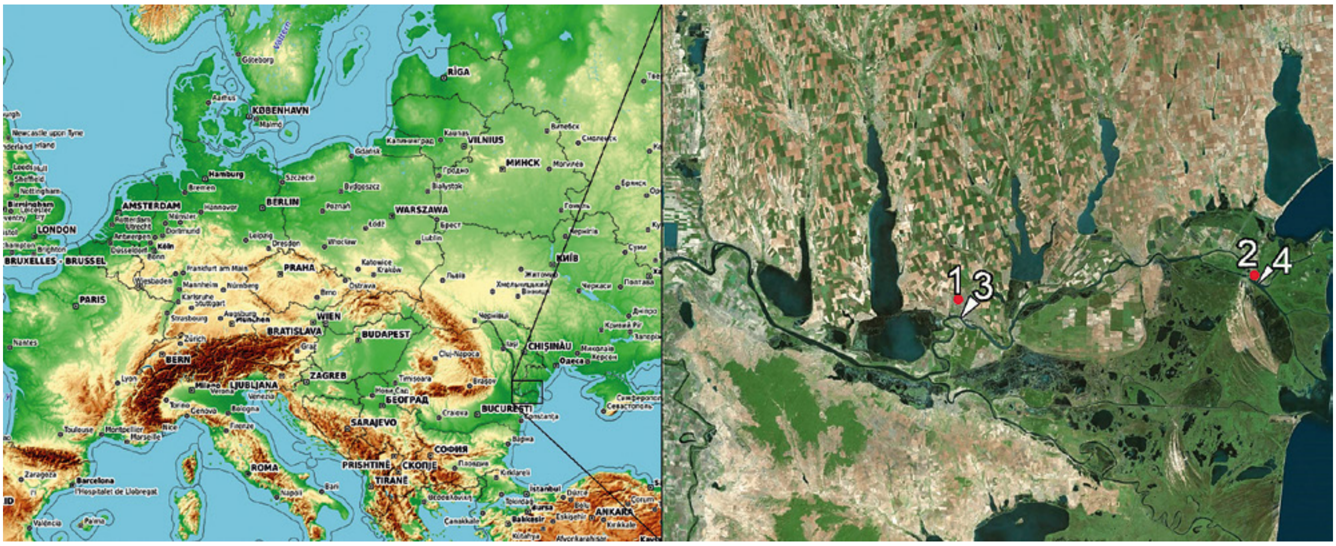

Figure 1. The location of the studied area: 1 – Izmail meteorological station, 2 – Vylkove meteorological station, 3 – Izmail hydrological station, 4 – Vylkove hydrological station

Introduction

The Danube Delta is the second largest in Europe after the Volga Delta. The length from its top to the sea edge in a straight line is 80 km. Approximately the same is the length from the north to the south. According to book edited by Mykhajlov (2004) this area is estimated at 4200 km^2, including the Ukrainian part – 830 km^2, the Romanian one – 3370 km^2. Other sources report an area of 4152 km^2 (Romanian part = 3446 km^2; Olson & Krug 2020). If we consider the Razim-Sinoe Lagoon as part of the Danube Delta, the total area reaches 5,165 km^2 (Olson & Krug 2020). In general, the boundaries of the delta and, accordingly, its area are somewhat debatable.

The location in the south-east of Europe and the abundance of water determines the richness of the delta biodiversity. In turn, the state of this richness depends on many factors. One of them is the climate and its change. There are many studies devoted to climate change in the Danube Delta and its consequences (Covaliov et al. 2022; Gastescu 2009; Mikhajlov et al. 2004; Stagl & Hattermann 2015; Stan et al. 2016; Vyshnevskyi & Shevchuk 2022). According to these studies, the air temperature in the delta is rising. The last years in the delta occurred not only warmer than usual, but very dry. In this regard, the main purpose of this study is to identify the features of climate change in the delta and its impact on other natural components of the delta ecosystem.

Materials and methods

There are two meteorological stations near the Ukrainian part of the Danube Delta: Izmail and Vylkove. Meteorological station Izmail is located on the northern outskirts of Izmail City, 4.7 km from the Danube River, meteorological station Vylkove is located almost on the river bank. Hydrological stations are located in the same cities. This gives the opportunity to study not only changes in air and water temperature but the correlation between these parameters (*fig. 1*).

Air temperature at meteorological stations is measured every 3 hours, and water temperature at hydrological stations at 8:00 and 20:00 local time.

Evaporation from the water surface in the Danube Delta was estimated on the basis of data from meteorological station Vylkove, where the observations are carried out using a GGI-3000 evaporator, the water surface of which is 3000 cm^2.

In addition to regular monitoring data, remote sensing data have been used. Most attention was paid to the images of Landsat 8 and Landsat 9 satellites, and Sentinel 2 satellite (available at https://scihub.copernicus.eu and https://earthexplorer.usgs.gov). The downloaded images were processed using ArcMap 10 program. Data from the Fire Information for Resource Management System (https://firms.modaps.eosdis.nasa.gov) was also used to analyze fires in the Danube Delta.

Results and discussion

The available data about mean annual air temperature offer the possibility to determine not only characteristic features

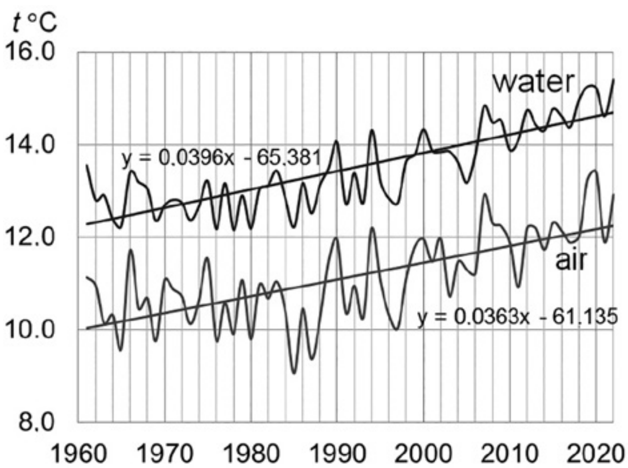

Figure 2. Changes of mean annual air and water temperature at Izmail meteorological and hydrological stations in 1961–2022

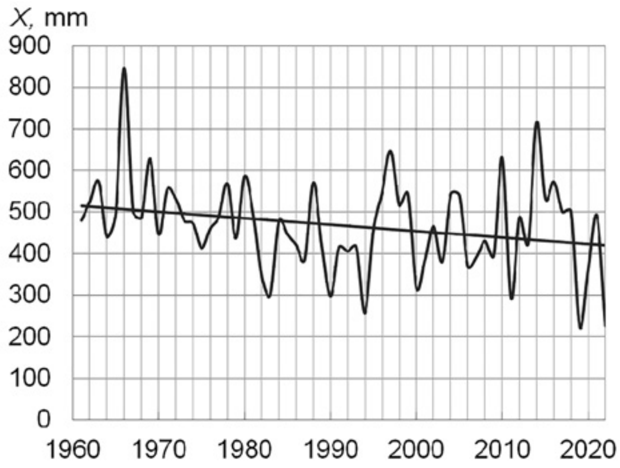

Figure 3. Changes of averaged annual precipitation at Izmail and Vylkove meteorological stations in 1961–2022

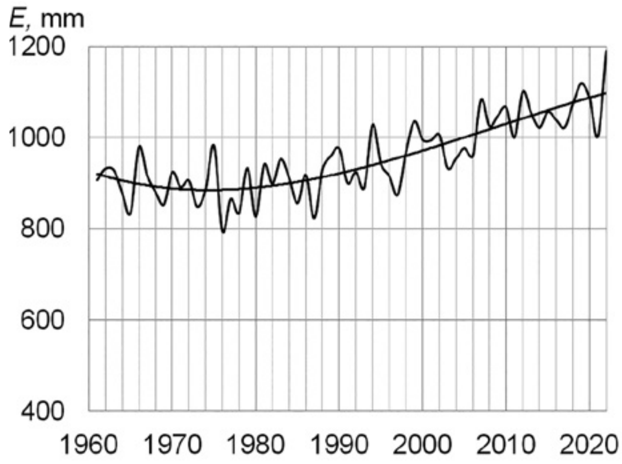

Figure 5. The changes of the calculated evaporation from water surface at Vylkove meteorological station in 1961–2022

of the climate in the studied region but also its changes during the last decades. The mean annual air temperature at Izmail meteorological station during the standard observation period of 1991–2020 was 11.7 °C, and at Vylkove station 12.2 °C. Over the past 60 years, namely 1961–2022, the mean annual air temperature in the studied area has increased significantly. The changes during this period was about 0.36 °C per decade. The highest air temperature for the entire observation period was in recent years, namely in 2019, 2020, and 2022 (*fig. 2*).

It is important that the water temperature in the Danube Delta is essentially higher than the air temperature with a difference of more than 2 °C. This excess is not stable during the year. The largest difference is observed in October when the mean air temperature at Izmail station is 11.9 °C and the mean water temperature is 16.1 °C. Even in March and April, when a rapid increase of the air temperature is observed, the water temperature is higher than the air temperature. The largest increase in water temperature is observed in July and August, the lowest in April. In recent years, the mean water temperature at Izmail station in July and August exceeded 26 °C.

As can be seen in figure 2, there is a good correlation between mean annual air and water temperature. The strongest correlation (r = 0.916) is observed between the annual values. A slightly lower correlation is observed in the warm period from May to October (r = 0.906). As for individual months, the closest correlation is observed in August (r = 0.891). On the other hand, the weakest correlation between mean air and water temperature is found in December and January.

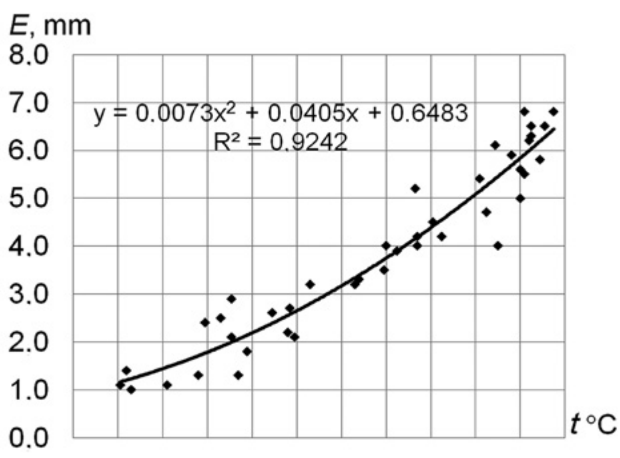

Figure 4. The dependence between air temperature and evaporation from water surface at Vylkove meteorological station

Another important factor influencing the Danube Delta state is the amount of precipitation. The mean annual precipitation at Izmail meteorological station during 1991–2020 was 449 mm, at Vylkove station 463 mm. In the previous 30 years (1961–1990) the precipitation was slightly higher, i. e. 490 and 481 mm, respectively.

As the precipitation is characterized by considerable spatial and temporal variability, averaging was carried out at the two mentioned meteorological stations to assess the changes. It turned out that the smallest precipitation was in 2019 and in 2022 (*fig. 3*).

According to the available observations at Vylkovo meteorological station, the daily evaporation layer on summer days can reach 6.0–7.0 mm and the monthly evaporation can exceed 200 mm. It was identified that evaporation from the water surface is highly dependent on air temperature. It is important, that this dependence is nonlinear. The same results were obtained for many meteorological stations and for different conditions (Vyshnevskyi, 2022) (*fig. 4*).

Based on the obtained dependence shown in Fig. 4 it is possible to determine the changes in evaporation from the water surface over a long period (*fig. 5*).

These data show that in recent decades, evaporation from the water surface has increased significantly from about 900 mm to 1100 mm. The obtained result is similar to that given for the adjacent territory of Romania (Neculau & Stan 2016), where an evaporation of more than 1000 mm was determined as well.

The results presented in (Vyshnevskyi 2022), show that the evaporation from the evaporation basins used at some meteorological stations (water surface is 20 m^2), is slightly smaller than from the evaporator GGI-3000 due to less water heating. It is about 0.9 from the data of evaporator GGI-3000. With this in mind, we obtained the mean annual evaporation from the water surface for different periods: 1991–2000 – 853 mm, 2001–2010 – 905 mm, 2011–2022 – 958 mm.

These data suggest that a part of the river flow in the Danube Delta is lost as a result of evaporation, as it is twice larger than precipitation. In the summer period the mean evaporation layer exceeds precipitation by about four times.

It should be kept in mind that most of the delta is not a water space. The main territory is covered by shallow water areas with air-water plants, which is dominated by reeds (Covaliov et al., 2022). According to the studies carried out in Romania (Stan et al., 2016), evaporation from such aquatic areas is about twice as much as evaporation from the water surface. It means that evaporation from such water bodies can reach 1900 mm and the excess of evaporation over precipitation is equal to 1450 mm. According to these data, it is possible to estimate the loss of water in the Danube Delta due to evaporation. Taking into account the delta area of 4200 km^2, the additional evaporation from natural landscapes can be estimated as 4–5 km^3. This is quite a noticeable value even for such a large river as the Danube (Vyshnevskyi & Shevchuk, 2022).

The increase of evaporation mostly impacts those parts of wetlands which are remote from the branches of the Danube River. In the Ukrainian part of the delta, such a problematic area is the Stentsivsko-Zhebrijanivsk wetland which is the most northern part of the delta. The lack of water has repeatedly affected the ecological state of this territory, but the most dramatic situation was in the fall of 2022. As a result of extreme arid conditions and the human factor, a large part of this wetland was burned (*fig. 6*).

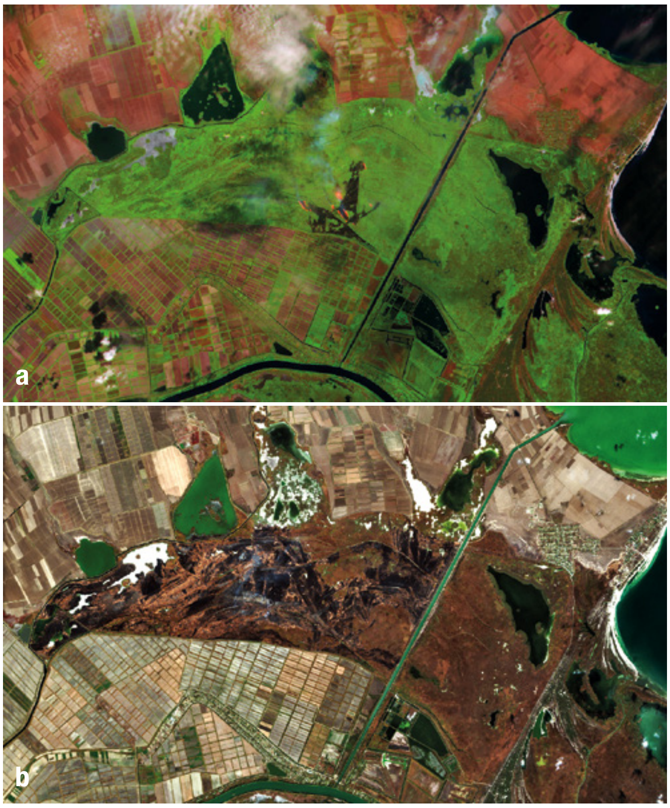

Figure 6. The burning reed and the burned Stentsivko-Zhebrijanivsk wetland on Sentinel 2 satellite images: a – on 29.09.2022, b – on 20.10.2022

Figure 7. The burning reed on the satellite images of MODIS Aqua and MODIS Terra satellites: a – on October 14, 2022, b – on October 28, 2022

Figure 8. The salt marshes in the northern part of the Danube Delta wetland on Sentinel 2 satellite image on 29.10.2022

The satellite images obtained from the Fire Information for Resource Management System show that burning in the Ukrainian part of the delta started on September 28, 2022 and lasted until October 21, 2022. Two weeks later (October 14. 2022) the fires started in the Romanian part of the delta. They lasted till November 10, 2022 (*fig. 7 a and b*).

In the dry autumn of 2022, many shallow lakes in the Danube lakes dried up and turned into salt marshes. It can be assumed that the increase in the salinity of water became common features of many lakes (*fig. 8*).

Analysis of the satellite image in fig. 8 indicates that in the fall of 2022, the algal bloom also became significant.

Conclusions

During last six decades the air and water temperatures in the Danube Delta increased by more than 2 °C. Simultaneously, a small decrease of precipitation was observed. The smallest precipitation was observed in 2019 and 2022. In general, the climate in the studied region became drier than it was at the beginning of the observation in the 1960s. According to the air temperature increase an increase of evaporation from the water surface was identified. Such changes concern all Danube wetlands. During last years, many fires occurred, which comprised large areas. The most wide spread fires happened in autumn 2022. At this time, some shallow lakes fell dry and transformed into salt marshes.

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Monitoring floodplain succession on the created lower reaches of the New Traisen

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DOI: 10.5281/zenodo.10257987

Abstract

In the context of a LIFE+-project 'Habitat in the estuary section of the river Traisen', the artificial channel in the lower course of the river Traisen (Lower Austria) was replaced by a newly created, near-natural riverbed within a broad, lowered floodplain corridor. In the course of vegetation ecology monitoring, succession, and in particular, the development of woody plants and the impact of alien plants are documented. The created connectivity between the river and its floodplains and the successful regeneration of the native woody species, the restoration goal of creating a near-natural floodplain ecosystem can be considered successful.

Introduction

The Traisen has its origin in the northern Limestone Alps and flows into the Danube on the right bank at Traismauer, approx. 50 km west of Vienna. During the construction of the Altenwörth Danube hydropower plant in 1973, the lowest section of the Traisen was channelled into a 7.5 km long artificial canal past the impounded Danube and its mouth was relocated downstream of the hydropower plant. The area is part of the Natura 2000 site 'Tullnerfelder Donauauen European Nature Reserve'.

The restoration concept intended to replace the canal-like Traisen section with a new meandering river course ('New Traisen') within a lowered floodplain corridor up to 300 m width (*fig. 1 and 2*). The project was implemented between 2014 and 2017. It is one of the largest river restoration projects in Austria and was co-financed by the LIFE+-project 'Habitat in the estuary section of the river Traisen' (Egger et al. 2018). The LIFE+-project's objectives were the creation of near-natural water and floodplain biocoenoses and an increase in biodiversity as well as the establishment of softwood riparian forest (FFH habitat type 91E0*). In the context of an accompanying monitoring program, the development of the vegetation was documented regularly, starting with the completion of the first construction phase in 2014 until 2021 (Egger et al. 2022).

Figure 1. The sinuous course of the New Traisen within the newly lowered floodplain corridor. On the right is the straight former Traisen canal. In the background is the Danube with its surrounding floodplain forests (© Pock/VERBUND).

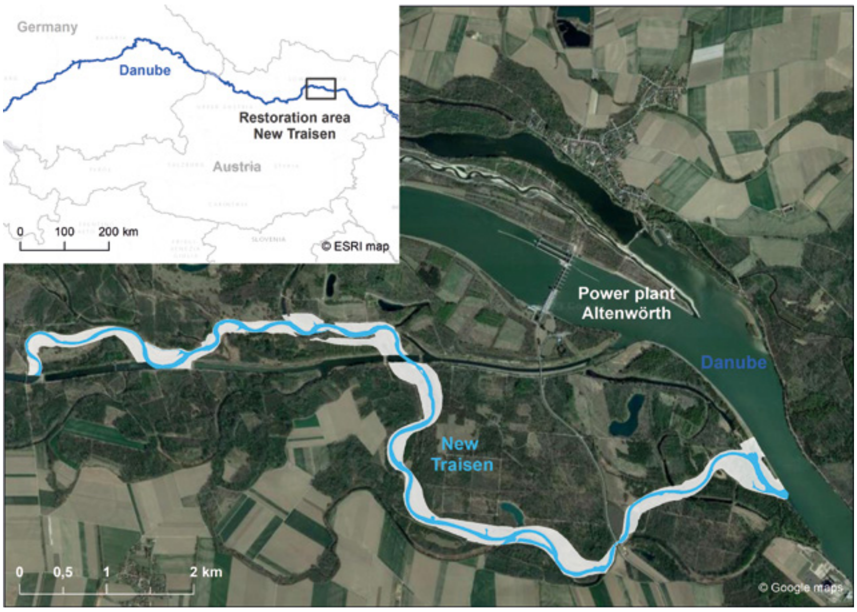

Figure 2. The newly created floodplain corridor (grey) and created river course (blue) in the LIFE+-project area in the lower section of the New Traisen.

Figure 3. Ruderal flora and young woody plants of black poplar and white willows in the lowered floodplain corridor one year after the restoration measure (© G. Egger).

Within just a few weeks, patchy pioneer vegetation and closed tall forbs, some with young willows (*Salix alba*) and poplars (*Populus nigra, P. canescens*), were able to establish on the freshly dredged areas. Floods were important for the rapid development, which led to sedimentation of silt and sand in the lowered corridor, creating optimal growth conditions with regard to water and nutrient balance. On the lowest bank areas in the wet to partially flooded areas, reed canary grass and rushes established while in the higher areas in the early years mainly tall herbaceous plants and sometimes ruderal vegetation as well as goldenrod stands prevail. The latter were able to spread increasingly over the years. In addition

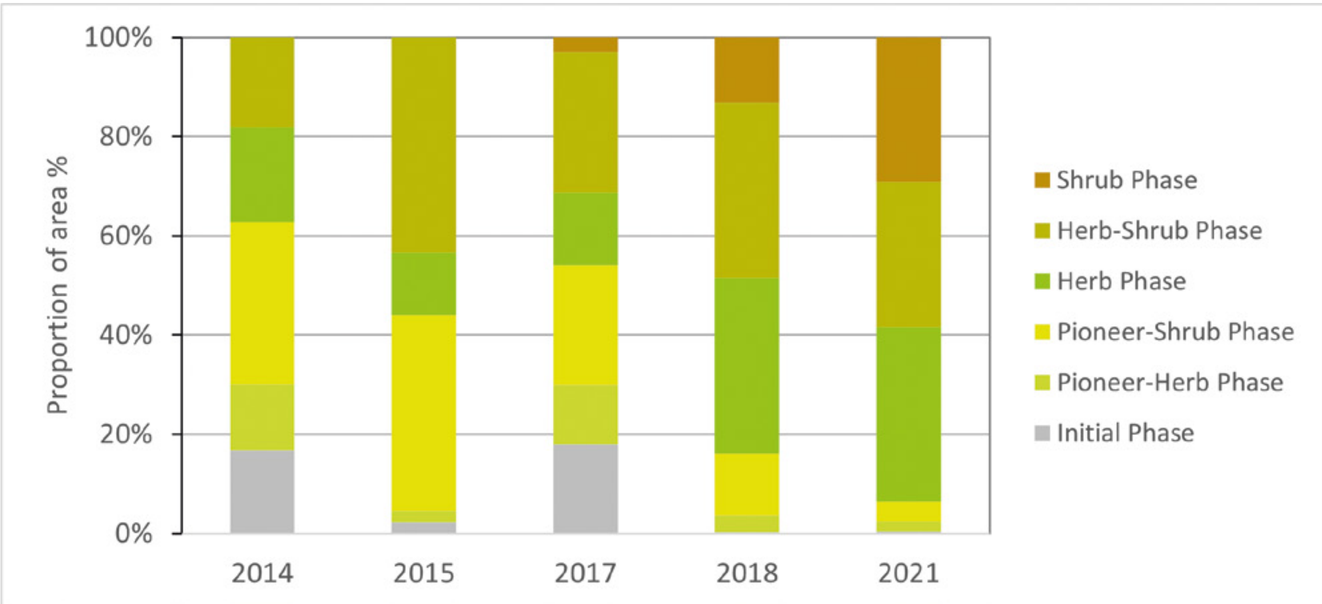

Figure 4. Area proportion of the succession phases in 2014, 2015, 2017, 2018, and 2021.

to herbaceous species, typical woody plants of softwood floodplains were also present from the outset. A closed shrub layer already formed on about 30 % by 2021. Mosaic stands of herbaceous plants and shrubs were able to establish on another 30 % (*fig. 4*).

In addition to favourable growth conditions, the low level of natural disturbance was responsible for this fast vegetation development. Floods hardly led to any destruction of the vegetation. Lateral erosion only occurred on the steep slopes of the New Traisen, resulting in small-scale sedimentation of gravel, sand and silt banks on the point bars. However, these were mostly quickly covered by vegetation again, so that in 2021 only 0.4 % of the total area was covered by an initial phase.

Development of the native woody plants of the softwood floodplain

On the young sites, it was mainly black poplar and to a lesser amount white willow that germinated. After a few years, grey poplar was also able to establish and spread vegetatively by root suckers. Average tree densities were very high in the first few years (up to 17 trees/m²). After the woody plants reached growth heights of 2 m to 3 m after three to four years, the density was reduced to approx. 0.3 to 2 trees/m² due to competition for light.

Impact of browsing on the number of woody plants

The impact of browsing by deer was investigated using fenced monitoring areas. These enclosures showed that browsing has a statistically significant impact on all woody plants in the area. It causes both a reduction in the number of individuals and a reduction in growth height by about fifty percent. However, analyses of time series revealed that in all cases browsing delays the development of woody plants but does not cause total failure.

Impact of the alien giant goldenrod on the development potential of FFH habitat type softwood riparian forests

By far the most relevant alien plant species in the project area is the giant goldenrod (*Solidago gigantea*). In the first few years, it only covered a small area in the pioneer vegetation and young herbaceous vegetation. This highly competitive species established itself preferentially on higher and drier sites and continuously formed denser stands here year after year. Vegetation types dominated by giant goldenrod cover more than a third of the study area in 2021.

The dominance of goldenrod stands was also investigated regarding the development potential of softwood floodplain forests (FFH habitat type 91E0*). In general, typical woody plants of the softwood floodplain such as poplar, willow and alder are able to establish, grow and develop within goldenrod stands. Thus, up to a goldenrod cover of 80 %, there is a clearly positive development of woody plants. A reduction in the average growth height and a reduction of density in 15 to 30 % of the areas could only be observed when the goldenrod covers 80 % or more. Regarding the positive net balance of woody plant development on almost all subplots, however, the impact of the giant goldenrod on the development of the softwood riparian forest is generally low in relation to the whole restoration area. Besides, further development and growth of the woody plants will inevitably reduce goldenrod cover.

Summary and outlook

The monitoring results show that the areas within the lowered floodplain corridor will develop into a mosaic of patchy to close softwood riparian forests of FFH habitat type 91E0* in about 10 to 15 years. Individual wood-free islands will remain in small areas such as the wet and frequently flooded areas near the banks covered by reed canary grass. In small areas, individual goldenrod tall herbaceous meadows may still survive in slightly higher locations. Therefore, we expect that the overarching objectives of the LIFE+-project such as the creation of natural and near-natural water and floodplain biocoenoses and an increase in biodiversity as well as the establishment of a softwood riparian forest (FFH habitat type 91E0*) will be achieved.

Due to the low natural disturbance influence, new, open pioneer areas are only created locally in small areas. The main reason is that the former Traisen canal still exists and that the water is partially diverted into this channel during floods starting at HQ1. The formation of young pioneer sites, which need the input of bedload material, is a requirement for the long-term establishment and preservation of a living floodplain. To increase the proportion of young successional areas and to prevent over-aging in the long term, an increase in natural river dynamics would be essential. Hydrodynamics must improve by discharging the entire flood into the New Traisen.

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Acknowledgments

This work is based on the results of the monitoring financed by VERBUND Hydro Power GmbH (Vienna). The preparation of the publication was supported by funds from the Schweisfurth Foundation in the context of a doctoral scholarship for Isabell Becker. We would particularly like to thank Christian Damm (KIT) for proofreading the manuscript.

ISSN 2070-1292

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Catchment of the River Danube

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Druckwerk24, Wolfgang Rückel
Eisengasse C125,
D-86633 Neuburg a.d. Donau