Fish Migration Restoration Document

2022

Interreg
Danube Transnational Programme

VÝSKUMNÝ ÚSTAV VODNÉHO HOSPODÁRSTVA
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Fish Migration Restoration Document

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Bratislava, 2022

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Abbreviations:

DSTF Danube Sturgeon Task force
EU European Union
EUSDR European Strategy for the Danube Region
GWP CEE Global Water Partnership Central Eastern Europe
FPC Flood pulse concept
HPP Hydropower Plant
ICPDR International Commission for the Protection of the Danube River
IUCN International Union for Conservation of Nature
PA Priority Area
RCC River continuum concept
WFD Water Framework Directive
WS Water Structure
WWF World Wildlife Fund

1. Introduction

Migratory fish species are extremely exposed to human activities, which cause deterioration of their habitats by hydropower generation, hydromorphological alterations, barriers construction, but also overfishing, rising water pollution and climate change. Blocking their migration routes through dams, and the loss or degradation of habitats causes disruption of their natural life cycle and leads to rapid and drastic decrease of their population. Considering these reasons, the populations of migratory freshwater fish species have plummeted globally by 76% on average since 1970, including a 93% collapse in Europe. Therefore, to deepen investigation for design and construction of effective fish passes in the Danube River, restore fish migration and maintain precious fish species (e.g. sturgeon) for future generations are crucial issues.

Sturgeons are a unique species of fish whose origins can be traced back over 200 million years. According to the International Union for Conservation of Nature (IUCN) over 85% of sturgeon species are classified as being at risk of extinction, thereby making them more critically endangered than any other group of species. Threats to their survival are numerous, the most serious being over-exploitation and poaching (exacerbated by poor fishery management and insufficient legal enforcement of fishing bans), blocked migration routes through dams, the loss or degradation of habitats, water pollution and climate change.

Danube region is currently facing the problems that threaten their survival, i.e. restoring migration routes and fighting overexploitation. The hydropower dams – Iron Gates I and II- today represent the biggest barrier to migrating fish in the Lower Danube. As a result, populations of migratory fish, such as sturgeons were diminishing in the past. Currently, most of the surviving sturgeon populations are confined to the Lower Danube, the 850 km long stretch of the river between Black Sea and Iron Gates. There is however, one exception – a sterlet sturgeon that still occurs in the Middle and some parts of the Upper Danube River. The dams effectively block all access for migrating fish to the middle reaches of the Danube and its tributaries (Drava, Sava and Tisza), all of which are vital spawning and nursery grounds for migratory fish. The international teams work intensively on investigation and design of effective fish pass in Iron Gates and moreover, the works on fish pass design have started in upstream barrier – Gabčíkovo – Čunovo water structure. Making the dams passable would recreate access to 800 km of the sturgeon's traditional habitat and spawning grounds in the Middle Danube. Therefore, this will greatly increase the sturgeon´s current freshwater range and significantly enhance the chances of population recovery.

Moreover, the conservation of sturgeon face the challenge to stop overexploitation and illegal fishing. Although most sturgeon caviar today comes from aquaculture facilities, caviar from systematic poaching is still finding its way onto the market. A 2013 WWF study determined that illegal fishing activities and the caviar trade was a severe threat to the future of Danube sturgeons. It is obvious that there is a need to build the capacity to pursue poaching, smuggling and illegal trade. In addition, also to promote public awareness of the plight of the sturgeon.

The revised EU Strategy for the Danube Region (EUSDR) Action Plan, adopted in 2020, boosts a more committed involvement of all stakeholders for the implementation of the Danube Region Strategy. The activities and objectives of the Strategy were updated to make a better interlinkage among them, with the EU Cohesion Policy and to facilitate more efficient use of the EU funds.

The EUSDR supports the topic of migratory fish conservation via Pillar II – Protecting the environment in the Danube Region, which unifies three Priority Areas (PA) - PA4 "Water Quality", PA5 "Environmental Risks" and PA6 "Biodiversity".

Priority Area 4 "Water Quality" (PA4) promotes measures to enable fish migration in the Danube River basin as stated in the Action 5 of Action Plan:

- raising broad public awareness and political commitment for the Danube sturgeons as flagship species for the Danube River basin and for the ecosystems and biodiversity of the Danube River basin as a whole;
- fostering sturgeon conservation activities including protection of habitats, restoration of fish migration routes and ex-situ conservation measures; and
- closing knowledge gaps concerning monitoring of pressures and planning of measures for fish migration in coordination with PA 6 (Action 3).

In line with the above-mentioned goals PA4 supports the preparation of the Fish Migration Restoration Document financed by Interreg Danube Transnational Programme and carried out by the Water Research Institute.

The purpose of this Document is to provide a knowledge base of current information on migratory fish restoration, e.g. overview on behaviour of fish species and ichtyocenoses, and contemporary state of play on alternative technical solutions of fish pass design for migratory fish at Gabcikovo Water Structure (case study). The Document could serve as the basis for searching for synergies with the international activities in Iron Gates I and II investigation for fish pass design and construction.

2. Strategic documents overview

The Danube River Basin Management Plans (DRBMP) developed under the EU **Water Framework Directive 2000/60/EC** (WFD) require the ongoing improvement of environmental conditions for all flora and fauna in the Danube region. With their long reproductive cycles and extensive migratory patterns, sturgeons are extremely sensitive to environmental pressures, making them valuable indicators for healthy rivers. The sturgeon has naturally benefitted from the EU legal framework.

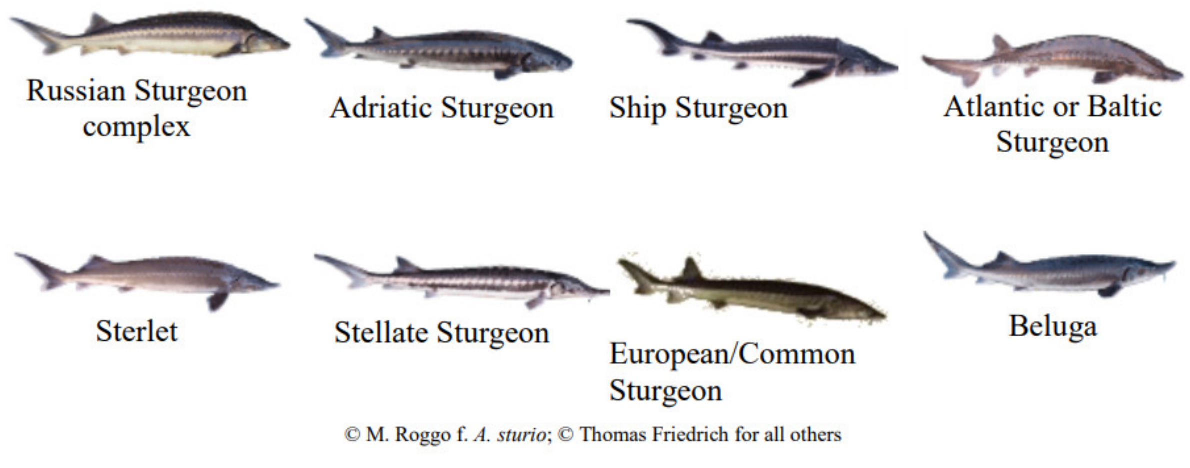
In order to ensure the survival of Europe's most endangered and vulnerable species, EU governments adopted the **Habitats Directive** in 1992 **(Council Directive 92/43/EEC** of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora**)**. This Directive forms the cornerstone of Europe's nature conservation policy and establishes the EU wide **Natura 2000** ecological network of protected areas, safeguarded against potentially damaging developments.

The European Commission also issued the **European Red Lists of Threatened Species**, developed by the IUCN, to provide an overview of the conservation status of about 6000 European species, so that appropriate action can be taken to protect those threatened with extinction. IUCN Red List Status Europe's freshwater fish species belong to a number of different families, which are varying both in species numbers and in the relative threat status of their species. The most threatened group are the sturgeons. All but one European sturgeon species depend on artificial reproduction and stocking for their survival.

The European Commission has published guidance on species protection to help Member States implement correctly the directive's provisions. **EU Species Action Plan**s are developed to restore the populations of certain species across their range within the EU. The **Pan-European Action Plan for Sturgeons** was adopted by the Standing Committee of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) in November 2018. It was recommended for implementation under the Habitats Directive in May 2019. This multi-species action plan covers 8 European sturgeon species, 7 of which are listed as critically endangered on the IUCN Red List of Threatened Species, while one is classified as vulnerable to extinction (Fig. 1):

Russian sturgeon complex (Acipenser gueldenstaedtii, A. persicus-colchicus),
Adriatic sturgeon (Acipenser naccarii),
Ship sturgeon (Acipenser nudiventris),
Atlantic/Baltic sturgeon, (Acipenser oxyrinchus),
Sterlet (Acipenser ruthenus),
Stellate sturgeon (Acipenser stellatus),
European/Common sturgeon (Acipenser sturio),
Beluga (Huso huso).

Figure 1: IUCN Red List of Threatened Sturgeons



The Plan sets the framework to conserve the last surviving sturgeon populations, protect and restore their habitats and migration routes, urgently end their illegal fishing and by-catch and reintroduce the species to a number of rivers. The geographical scope of Plan are the European Union and neighbouring countries with shared basins such as the Black Sea, Mediterranean, North Eastern Atlantic Ocean, North Sea and Baltic Sea. The lifespan of the Plan is ten years (2019 – 2029).

The International Commission for the Protection of the Danube River (ICPDR) realised the importance of this unique fish and endorsed sturgeons native to the Danube as a flagship species. This commitment was emphasized on the occasion of the Danube Ministerial Conference in December 2016 where the **ICPDR adopted sturgeons as a flagship species** and reiterated at the annual Ordinary Meeting in Vienna in December 2017 with the announcement of the adoption of the Sturgeon Strategy. The ICPDR works closely on this matter with their partners in PA 4 (Water Quality) and PA 6 (Biodiversity) of the EUSDR.
The principal aims of the strategy are:

- to raise awareness of the sturgeon’s plight
- to promote existing and future projects, initiatives and EU Directives to enhance environmental conditions for the sturgeon
- to develop specific solutions to the specific problems that the sturgeon is currently facing.

The **Danube Sturgeon Task force (DSTF)** was developed by the ICPDR jointly with the EUSDR PA6 (Biodiversity) in 2012 with exactly these objectives in mind, and has since been striving to achieve the objectives of the current strategy by promoting the implementation of the **‘Sturgeon 2020’ programme**. Key measures for ‘Sturgeon 2020’ include the setting up of a pilot ex-situ facility for migratory species and in-situ monitoring of habitats and population behaviour along the Danube and its major tributaries. In addition, cooperation with contracting fish farms will facilitate the creation of an inventory of captive sturgeons. The establishment of national sturgeon conservation networks to foster the implementation of ‘Sturgeon 2020’ at national levels is also envisaged. The specific measures focus on ensuring the integrity and viability of migration routes (especially Iron Gate I and II hydroelectric dams and Gabčíkovo waterworks), the existence of appropriate spawning grounds, appropriate ecology and water quality along migration routes and at spawning and nursery grounds.

At national level, there are binding documents for fish passes design, which meet EU legislation. The fish passes in Slovakia should meet the requirements related to technical parameters, feasibility and effectiveness of fish passes in accordance with the Regulation of the Ministry of Environment of the Slovak Republic No 383/2018 Coll. on technical conditions for fish passes design and monitoring of migrating capacity of fish passes. In addition to legal requirement, there are a methodical guidance of the Ministry of the Environment of the Slovak Republic (2015) “Definition of suitable types of fish passes in accordance with typology of water courses” and the Slovak Technical Standard STN EN

17233: Water Quality: Guidelines for efficiency assessment and related metrics of fish passes by telemetry.

In addition, the Hungarian National Water Strategy also deals with the issue of longitudinal connectivity with regard to EU legislation (WFD). Among the measures which are necessary to achieve a good ecological potential, the establishment of fish passages is listed in order to restore longitudinal connectivity. There are no requirements in the Hungarian legal system regarding the parameters of effective fish passes. However, in Hungary, there is valid a guide to fish pass design with technical details based on an FAO publication (available in Hungarian), but it is only a recommendation, not mandatory (information kindly provided by Dr. Gabor Guti).

3. Overview of different types of migration behaviour

Migration is an important behavioural pattern that can be generally defined in ecological terms as the large scale movement of a species to a different environment. Migration in freshwater environments is generally associated with aggregation of many individuals in shallow waters. This is mainly because such aggregation is easy to spot even for the casual observer. Due to ease of observation, fish migration in broad terms is usually connected with several species that exhibit strong migration behaviour (e.g. spawning migrations of sterlet, barbel, nase, and Danube salmon or vimba bream). However, migratory movements of fishes do not always involve high concentration of individuals. It is very important to clarify that all fish species exhibit migration patterns on different scale (spawning, feeding, refuge migration or dispersion) and no fish species should be labelled as non – migrant or stationary. Migration behaviour can therefore be considered as an important part of life cycle of fish species and obstruction or restricting of migration routes can lead to serious consequences. In fact, human impacts on the Danube River and its tributaries over the centuries caused substantial changes in their morphology and biota with the most affected group being migratory fish species. In the past, negative impacts, such as construction of migration barriers, over-catching, degradation and fragmentation of habitat led to decline in fish stocks. However, in the present poaching is seen as one of the strongest stressors for persisting sturgeon populations. This trend was especially noticed in economically important fish species, such as sturgeons. Up to this date, the decline in fish stock density is affecting several species. This section will provide basic overview of importance of the fish migration from ecological viewpoint.

Migration behaviour of fish species is highly complex issue that is beyond the scope of this document. For purpose of this section a short summary is presented to provide insight into fish migration.

Migration behaviour of fish was studied extensively in the past as well as in present. There are several definitions and views on fish migrations available up to this date. For example, definition by Northcote (1978, 1984) describes migration as follows: movements that result in alternation between two or more separate habitats, occur with a regular periodicity within an individual´s lifetime, involve a large proportion of the population and involve directed movement at some stage of the lifecycle. Seasonal movements are included as long as they are between distinct habitats and fulfil the other criteria.

A huge emphasis was put on studying fish migration between salt and freshwater. With respect to environmental conditions, three types of migration are defined as follows:

1. **Oceanodromy**
   This type of migration represents movement within saltwater habitats. Oceanodromous fish species spend their entire life in saltwater.
   Example: Atlantic Bluefin Tuna (*Thunnus thynnus)*.
2. **Potamodromy**
   This type of migration represents movement within freshwater habitats. Migration can occur on longitudinal scale (upstream, downstream migration) or lateral scale (movement from river to floodplain and vice versa). Potamodromous fish species spend their entire life in freshwater.
   Example: Barbel (*Barbus barbus*)
3. **Diadromy**
   Diadromous fish species migrate between saltwater and freshwater habitats during their life cycle. There are different types of diadromous fish:
   a) **Anadromous**
      Anadromous fish species spend most of their life in saltwater and migrate upstream to freshwater rivers for reproduction.
      Example: Beluga sturgeon (*Huso huso*)
   b) **Catadromous**
      Catadromous fish species enter freshwater habitats as juvenile. When reaching maturation, they migrate back to saltwater for spawning.
      Example: European eel (*Anguilla anguilla*).
   c) **Amphidromous**
      Fish that migrate between freshwater and saltwater for any other purpose other than breeding.
      Example: Torrentfish (*Cheimarrichthys fosteri*)

In accordance with the purpose of migrations there are three main functional categories:

1. **Spawning migration:** migration for the purposes of reproduction
2. **Feeding migration:** for seeking food resources or minimizing competition
3. **Refuge migration:** for seeking refuge from unfavourable conditions

Different fish species carry out these migrations in different time with respect to their autecology. Furthermore, there can be a wide variety of both external (i.e. temperature) and internal (i.e. genetic and life history related) triggers for migration.

Furthermore, there are also other reasons for fish migration. For example, fish might move on a daily scale in a small area (diurnal movement). They might flee or avoid predators, search for suitable habitat or naturally disperse to reduce competition.

4. River ecosystems

Freshwater habitats occupy roughly <1% of the Earth´s surface yet can be deemed as hotspots that support roughly 10% of all known species and about 40% of fish species worldwide. For the purpose of this document, we will be focusing on river ecosystems.

Rivers are considered among most diverse and productive ecosystems on the planet. Their defining characteristics – flowing water – keeps the physical conditions of life changing constantly. In fact, rivers and streams represent one of the most dynamic of the freshwater aquatic environments. Flowing water is one of the main factors that shapes and reshapes river channels, streamside areas, floodplains, creates riffles and pools. In other words, it is a driving change that results in habitat diversity. It is important to consider that not all of this changes can be visible to human eye, especially in large scale rivers (e.g. movement and deposition of sediment) for many years. Moreover, volume of flow changes dynamically with large scale differences not being uncommon. For all aquatic organisms including fish, these constant changes of environment provide both opportunities and dangers. In the long lasting evolutionary process aquatic organisms became adapted to variety of conditions, learning to exploit some conditions while effectively dodging unfavourable conditions. Variety of adaptations ranges to such a scale that even what would be deemed unfavourable from human perspective (i.e. floods) can be utilized by certain species to some extent. In fact, movement in general is one of the main options available to fish when responding to changes in their environment.

For better understanding of how connectivity restoration can directly impact fish conservation, this section will provide a basic overview about four dimensional nature of lotic (running water) ecosystems based on the River continuum concept (RCC) and Flood pulse concept (FPC). Both concepts were extended, modified and even restricted by other scientists. Because these concepts are scientific, their application cannot be generalised or applied everywhere. They are used in this document to briefly describe complexity of river ecosystems and why are they important for fish communities.

4.1 Four- dimensional (4D) nature of lotic (running water) ecosystems

The River continuum concept (RCC) was first postulated by Vannote (1980) and describes the entire river system as a continuously integrating series of physical gradients and associated biotic adjustments as the river flows from source to mouth. This concept mainly takes into account longitudinal gradient of the rivers. Ward (1989) postulated that lotic ecosystems should be viewed on a four dimensional scale:

a) The longitudinal dimension

Provides connection between source and sink of the river. This involves nutrient, organic and inorganic matter transportation and free sediment flow as well as communication of different biological assemblages.

This dimension of ecosystem is often impaired by construction of migration barriers such as dams, weirs and sluices.

b) The lateral dimension

Provides connectivity between river and surrounding land, including inundation planes and wetlands.

This dimension of ecosystem is usually restricted by river channelization, bank stabilisation and cutting off and draining wetlands for agriculture purposes.

c) The vertical dimension

Provides connection with groundwater supplies

This dimension can be negatively affected by heavy river channelization or construction of big dams that might result in change of groundwater level.

d) The time dimension

Describes changes of river morphology and riverbed in time. Rivers are understood as highly dynamic systems that can be shaped in time (i.e. via morphology changes induced by flood events).

This dimension is highly affected by disruptions in longitudinal and lateral dimensions. For example, barriers can effectively function as sediment traps, drastically reducing sediment deposition under the barrier. Channelized river has limited potential to create new habitats.

It is important to highlight that these four dimensions are highly interconnected. Disruption in one of these dimensions caused by human induced change is most likely result in disruption of other dimensions.

4.2 Flood pulse concept

The flood pulse concept was first published by Junk et al. in 1989. This concept highlights the importance of how the periodic inundation and drought control lateral exchange of water, nutrients and organisms between the main river channel and connected floodplain.

In smaller streams (i.e. mountain brooks) flood pulses are usually unpredictable and brief. Therefore, the inhabiting biota usually has limited adaptations for utilizing inundation zones. Flood events are still considered important for sediment transportation and habitat creation in smaller rivers.

In larger rivers, such as the Danube, flood pulses usually last longer. This led to creation of wide variety of adaptations by organisms to utilize different attributes of inundation zones efficiently.

Managing flood pulses has become one of the key aspects of sustainable management and conservation of inland wetlands.

5. Negative impacts of human induced changes on fish migration

Humankind has been exploiting ecosystems for millennia, continuously changing their surroundings for drinking, irrigation, waste disposal, transportation, power production, harvest of food and minerals. However, due to utmost importance of water for life, freshwater ecosystems are facing faster degradation than any other ecosystem. Many of changes (i.e. regulation of rivers) were completed before the negative effects of such regulations were known to humankind. Even nowadays with variety of information available on negative impacts of such changes, we can still see negative impacts such as damming, unnecessary regulations and polluting of river ecosystems. While this topic is quite extensive, for purpose of this document we will go over several major impacts of human activity to highlight their impact on fish communities.

As stated, all fish species can be deemed as migratory and no fish species should be considered stationery. Some species exhibit stronger migratory behaviour then others. For example, sturgeons are highly migratory fish species and they often move hundreds of kilometres within rivers. Longitudinal connectivity of river is therefore seen as very important. Constructions of migration barriers has negative effects on all of freshwater fauna. However, fish species exhibiting heavy migration behaviour are among most affected. In their life cycle, fish species often utilise different habitats. Sturgeons are often known for altering between their feeding, spawning and overwintering sites. The precise location of such habitats is not always known in detail. Construction of migration barriers in any form (dams, sluices, impoundments, weirs) can lead to fragmentation of habitat and might render some parts of the river inaccessible for populations. Probably the best example of how obstruction of migration route can lead to destruction and loss of populations in some sections of the river is construction of Iron Gates I in 1972, Iron Gates II in 1985 and Gabčíkovo in 1992. Before the construction, five sturgeon species - sterlet (Acipenser ruthenus, Linnaeus 1758), Russian sturgeon (Acipenser gueldenstaedtii, Brandt 1833), ship sturgeon (Acipenser nudiventris, Lovetzky 1828), stellate sturgeon (Acipenser stellatus, Pallas 1771) and beluga sturgeon (Huso huso, Linnaeus 1758) – were considered abundant in the Danube River. After the construction of Iron Gates I, the decline of stocks has become more apparent thanks to high economical value of sturgeons. Complete blockage of migration route led to extinction of four native sturgeon species upstream of the Iron Gates barrage system. Currently, only one sturgeon – sterlet (Acipenser ruthenus, Linnaeus 1758) is present in the Middle and Upper Danube River.

Construction of barriers also forces surviving population to search for suitable habitats under the barrier. Because suitable habitat for sturgeons can be viewed as commodity, their availability is limited. This can lead to increased competition between species. Furthermore, limited availability and increased competition can lead to decreasing population density and in some rare cases it can increase the probability of hybridisation. It is important to stress out that sturgeons are spawning in cycles from every 2 to every 6 years depending on their autecology and that hybrids of sturgeons are mostly infertile. Therefore, hybridisation might result in a loss of limited reproductive potential of sturgeons.

Another problem rising from obstruction of migration routes is **limited dispersion**. It is common for young of the year fish to migrate into surrounding smaller rivers and brooks to escape unfavourable conditions or reduce competition. Cutting off these migration routes by building impoundments or sluices in the mouth of rivers effectively blocks these migration paths. As a result, younger fish are usually stuck under the barrier in high densities and face high predation risk from piscivorous predators (i.e. birds). These negative impacts lead to lower survival rate of brood stock and decline of population.

Construction of larger barriers does not block only migration routes, but also **changes character of the river upstream**. Impoundments might reach several kilometres upstream functionally changing the river ecosystem and natural flow of the river. Such changes might result in change of species community or trap fish in the impoundment. Even strictly reophilic (preferring fast flowing water) species such as nase (*Chondrostoma nasus*), barbel (*Barbus barbus*) or vimba bream (*Vimba vimba*) can survive in impoundments. However, they are unlikely to complete their reproduction cycle unless they migrate out of the impoundment and find suitable habitat above the barrier. Given the fact that larger dams function as sediment catchment, this change results in total destruction and loss of river habitat. Sediment catchment above the barrier might also pose significant problem for parts of the river below, especially if management of sediment is insufficient or entirely lacking. Sediment transport in river plays an important role when creating habitats for aquatic life. Different fish species require specific sediment size for their reproduction. Because aquatic environment is highly dynamic, habitats are often subject to change. That means that natural processes might create habitats in one section, while similar habitats might disappear in another section of the river. Catching sediment upstream coupled with disruption of natural flow regime might result in decreased availability of river to create new and suitable habitats for different fish species in some sections below barriers.

Larger dams can also have **significant impact on the flow regime of the river**. This topic is of course very case specific and depends on operating manual of specific construction. Dams or hydropower plants that release the same amount of water that reaches their impoundment might not affect flow regime significantly, unless they cause hydropeaking. However, some dams use bypass canals for hydropower production. In such case, a significant proportion of water is repelled from main river channel for hydropower production. These channels can vary in length and connect back with river after several kilometres. This creates a section of main river channel ranging from estuary of bypass canal up to the migration barrier that is usually hydrologically decoupled from normal flow regime. Because bypass canals are not accessible for fish species, main river channel might be unsuitable for migration due to unfavourable flow conditions. Deep dams with longer retention of water also create stratification. This hydrological phenomenon describes separation of water layers in the impoundment (epilimnion, metalimnion and hypolimnion). These layers are separated by their properties and temperature. Some dams might release water from the bottom (hypolimnion layer). Depending on where the dam is situated, released water from hypolimnion might be much colder. Especially in lowland rivers, colder water might disrupt migration cues for some fish species. Furthermore, releasing water from the bottom usually flushes out fine sediment. Linked together with different hydrological regime caused by water manipulation such conditions can effectively lead to degradation of habitats.

Another negative impact on aquatic communities in general is **hydropeaking** – a practice of hydropower dams that releases water pulses to increase electricity production to meet daily peak demand. Hydropeaking results in increases and decreases of water level periodically – usually in hourly scale. This fluctuation of water level might range in tens of centimetres. Fish communities must constantly react to different flow conditions caused by fluctuations of water levels. Higher peaks might even render some habitats inaccessible. Furthermore, younger fish can respond to rising water by moving along with the shoreline. Some of them might become trapped in ponds or depressions during recess and fall easy prey to predators. Hydropeaking during spawning period might also pose threat to reproductive success of certain fish species – especially those that spawn in shallow fast flowing waters. During the recess of water level, their eggs might stay ashore or conditions might become unfavourable for their survival resulting in loss of reproductive potential.

Stabilizing river banks, channelizing the river or alternating riverbed poses significant issues for fish communities as well. Channelized river lacks natural diversity of habitats. It is natural for rivers to meander and create shallow fast flowing areas and deeper pools. Straightened and channelized river has reduced potential for creating wide variety of habitats. Runoff in channelized streams is also faster and sediments cannot be deposited causing habitats to be relatively uniform. Young of the year fish species also inhabit shoreline areas. Their stabilization by concrete blocks or boulders might create unfavourable conditions for their survival. Some stabilisation types might create favourable conditions for spread of invasive fish species. For example it is know that rip-rap in the Danube River is often colonised by Baltic gobies.

Lateral connectivity spans beyond banks of the river. During flood pulses, water spills out into the surrounding areas and inundation zones bringing nutrients and washing away sediment in disconnected river branches or relocating organic material. During evolutionary processes, many fish species learned to exploit these inundation zones and they life cycle depends on periodical floods. For example, during flood events, vegetation becomes flooded. This might provide suitable spawning habitat for phytophylous fish species such as northern pike (*Esox lucius*) or ruffe (*Gymnocephalus cernua*). Other fish species, for example from spawning group of litho-phytophylous might not strictly require marcophytes for spawning, but can utilise accessible habitat for spawning as well. Flooded inundation zones are not only for spawning. Many other fish species are migrating to these zones to feed. According to Reinartz (2002), even sterlet sturgeon used inundation zones as feeding sites during flood pulses. Restricting access to inundation and disconnecting river branches by channelization of river leads to slow degradation of these habitats.

Disconnecting river branches entirely leads to accumulation of organic material and sedimentation. Without periodic flushing, these habitats are slowly disappearing. More often, such habitats are often inhabited by various rare and protected fish species such as European mudminnow (*Umbra krameri*) and the weatherfish (*Missgurnus fossilis*). Therefore, flood management in watersheds is an important part not only from migration viewpoint, but also as a conservational tool to preserve habitats and protected species.

6. Danube River ichtyocenoses overview

Danube is inhabited roughly by 100 freshwater fish species along its entire course. Native fish fauna in Slovakian – Hungarian stretch of the Danube River includes roughly 50 species. This relatively high number of species is thanks to Danube being important migration corridor that also contains inland wetlands. Inland river-flood-plain ecosystem with diverse branches with different connectivity creates rich habitat diversity for many fish species. There were several ichtyological surveys conducted in Slovakian – Hungarian stretch of the Danube River over the years. It is important to mention that these studies often had different goals and therefore comparing their results should be handled with care. However results of these studies can provide us with lists of species that inhabit Slovak – Hungarian section of the Danube River and inland delta. Summarised data about numbers of fish are provided in Table 1. Data about presence of certain species were added based on personal experience from monitoring of inland Danube delta during 2015 – 2019 (Pekárik & Kubala, unpublished data).

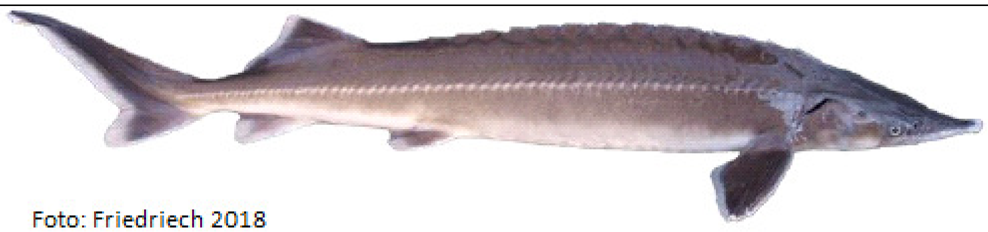
Table 1: Number of species confirmed in the Danube River from different sources (Nagy, 1994, JDS3, JDS3 + pers. observation of author, unpublished data).

Source	Native species	Non-indigenous species	Sum of species
Nagy, 1994	41	8	49
JDS3	26	6	32
JDS3 + pers. obs.	31	10	41

From native species, at least 22 of them can be labelled as full migrants and exhibit considerable migration behaviour spanning over several kilometres up to hundreds of kilometres. From 22 migratory fish species, 15 of them have been confirmed during JDS3 survey or in inland delta. That means that more than 1/3 of fish present in the Danube River today exhibit significant migration patterns with many other species that could benefit from reconnection of rivers as well. Due to the complexity of river ecosystems and extensive amount endangered species from different classes a **concept of “umbrella species”** was postulated. Requirements of umbrella species are supposed to represent requirements of many other species. Therefore any conservation measure that would help restore populations of umbrella species should also help other species. Due to highly complex life cycle, economical and recreational importance **sturgeons were deemed as umbrella species** and became symbol for reconnecting the Danube River Basin.

Few examples of migratory fish species that once occurred or are still present in the Danube River with short characteristics about their autecology (Table. 2):

Table. 2: Overview on migratory fish species in the Danube River

<table>
<tr><td colspan="4">Sterlet sturgeon
Acipenser ruthenus
Linnaeus 1758</td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td>Weight:</td><td>up to 16 kg</td><td>Migration pattern:</td><td>potamodromous</td></tr>
<tr><td>Length:</td><td>up to 1,2 m</td><td>Spawning periodicity:</td><td>2 years</td></tr>
<tr><td>Maturity:</td><td>Males 3 – 5 years</td><td colspan="2">Females 5 – 8 years</td></tr>
<tr><td>Maximum lifespan:</td><td>~25 years</td><td>IUCN status:</td><td>endangered</td></tr>
<tr><td colspan="4">Last sturgeon species that naturally spawns and inhabits Upper and Middle Danube River. Sterlet used to be one of most abundant sturgeon species in this section of the river in past. Its density began declining after construction of migration barriers (Iron Gates I, II, Gabčíkovo) due to complete blockage of migration route combined with unsustainable fisheries management and poaching. It´s highly reophilic species that inhabits depths in the Danube River. It appears that migration patterns of this species are controlled by water temperature and length of the day. It requires highly specific habitat for spawning (gravel and smaller stones with crevices) and larvae are dependent on highly oxygenated water. Similar to other Danube sturgeons, this species exhibits so called “home range” behaviour – it returns to the same known sites each year to feed, spawn and overwinter. This species is the only sturgeon naturally occurring in the Slovakian stretch of the Danube river.</td></tr>
</table>

Russian sturgeon

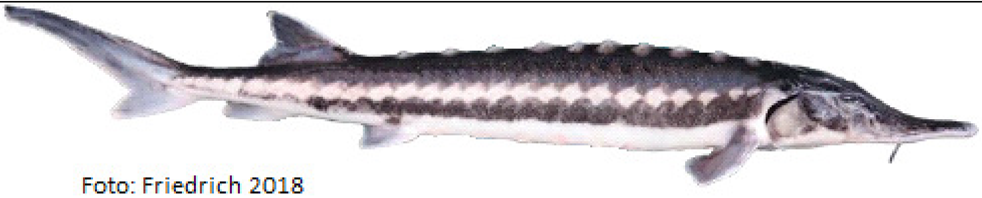
Acipenser gueldenstaedtii

Brandt 1833

Foto: Friedrich 2018

Weight:	up to 110 kg	**Migration pattern:**	anadromous
Length:	up to 2,4 m	**Spawning periodicity:**	2 – 6 years
Maturity:	Males 8 - 13 years	Females 12 - 16 years	
Maximum lifespan:	~50 years	**IUCN status:**	critically endangered

Once also considered abundant in the Danube River, Russian sturgeon populations disappeared from the Middle and Upper Danube River due to obstruction of migration route. Recent data suggests that fraction of population is still able to survive downstream of Iron Gates, however, limited habitat availability in this area might be concerning. Russian sturgeon requires migration to salt water to complete its life cycle. This species exhibits so called autumnal and vernal migrations in some rivers. Individuals that migrate on autumn utilise overwintering habitats and spawn on the next years. Spawning occurs mostly in main river channel on gravel or small stones in deep waters (4 – 25 m) with current about 1 – 1,5 $m.s^{-1}$.

<table>
<tr><td colspan="4">Stellate sturgeon
Acipenser stellatus
Pallas 1771</td></tr>
<tr><td colspan="4">
Foto: Friedrich 2018</td></tr>
<tr><td>Weight:</td><td>up to 80 kg</td><td>Migration pattern:</td><td>anadromous</td></tr>
<tr><td>Length:</td><td>up to 2,9 m</td><td>Spawning periodicity:</td><td>2 – 4 years</td></tr>
<tr><td>Maturity:</td><td>Males 6 - 8 years</td><td colspan="2">Females 8 - 12 years</td></tr>
<tr><td>Maximum lifespan:</td><td>~28 years</td><td>IUCN status:</td><td>critically endangered</td></tr>
<tr><td colspan="4">While this species was not very abundant in the past, it also became extinct in Upper and Middle Danube River due to blockage of migration routes. From historical data, this species migrated to Austria. The furthest detection of this species is dated in Straubing in Bavaria. This species spawns only under stable hydrological conditions as fluctuating conditions lead to high egg mortality. It spawns only in deep fast flowing sections of rivers with stone or gravely bottoms. Juveniles passively migrate into saline environment after hatching.</td></tr>
</table>

Beluga sturgeon

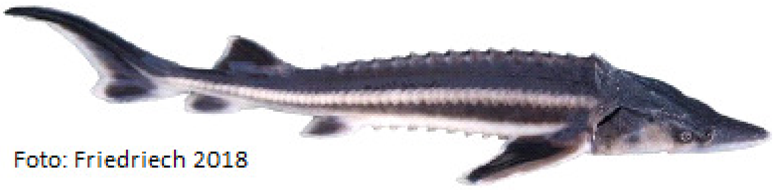
Huso huso

Linnaeus 1758

Foto: Friedrich 2018

Weight:	up to 2000 kg	**Migration pattern:**	anadromous
Length:	up to 8 m	**Spawning periodicity:**	3 – 4 years
Maturity:	Males 10 - 15 years	Females 14 - 20 years	
Maximum lifespan:	~60 years	**IUCN status:**	critically endangered

One of the most iconic sturgeon species that became symbol for Danube River connectivity restoration over the years. This species was considered very abundant. In fact, historical spawning sites were situated in the Middle Danube River. This sturgeon species played important role in fisheries creation in the Danube River. According to many historical and paleontological records,it was also important as a food source for settlements surrounding Danube River. Due to migration barriers, this species is also absent from Upper and Middle Danube River. While there are surviving populations in other basins, a small population endangered by poachers still exists under Iron Gates. Similar to Russian sturgeon, Beluga also exhibits autumnal and vernal migrations. Spawning takes place at temperatures from 6 – 14 °C and Beluga sturgeon can also utilize flooded areas as spawning grounds.

Ship sturgeon *Acipenser nudiventris* Linnaeus 1758			
 Foto: Friedriech 2018			
Weight:	up to 120 kg	**Migration pattern:**	anadromous
Length:	up to 2,2 m	**Spawning periodicity:**	1 - 3 years
Maturity:	Males 9 – 15 years	Females 12 – 16 years	
Maximum lifespan:	~40 years	**IUCN status:**	critically endangered

This species was one present in the Danube River basin. However, according to IUCN it is nowadays considered extinct even in the Lower Danube River. Resident populations are only known to survive in Georgia and Kazakhstan. This species also exhibits two migration runs – in spring and in autumn. Individuals migrating upstream in autumn overwinter in rivers and spawn on the next year. There is only little information about this species habitat preferences in the Danube River. Data from different river basins suggest that it can spawn on gravel and smaller rock bottom when water temperature reaches above 10°C.

Barbel

Barbus barbus

Linnaeus 1758

Weight:	up to 25, usually 5 – 6 kg	**Migration pattern:**	potamodromous
Length:	~ 1 m	**Spawning periodicity:**	3 – 4 years
Maturity:	males 2 - 5 years	Females 3 - 7 years	
Maximum lifespan:	~15 years	**IUCN status:**	least concern

Typical reofilic fish species that exhibits potamodromous migrations. Spawning migrations can be as far as 200 km long. It spawns on free flowing relatively shallow prats of the river with gravel or stone riverbed. Spawning takes place in intervals and males often accompany ripe females to spawning grounds. Their eggs contain special substance that invokes gastrointestinal problems when eaten. While this species abundance is not concerning, it is one of many examples of migratory fish that commit long spawning runs strictly in freshwater. Other examples potamodromous fish species that migrate several hundreds of kilometres are nase (*Chondrostoma nasus*) and vimba bream (*Vimba vimba*).

Common bream *Abramis brama* Linnaeus 1758			
			
Weight:	up to 11 kg	**Migration pattern:**	potamodromous
Length:	~ 75 cm	**Spawning periodicity:**	3 – 4 years
Maturity:	males 2 - 4 years	Females 2 - 4 years	
Maximum lifespan:	~15 years	**IUCN status:**	least concern
Even though it might not look like typical migratory fish species, Common bream can migrate as far as 100 km to spawn. Males of this fish species are territorial during spawning and defend their territories. It spawns on in areas with dense vegetation, along shorelines or on floodplains. This species can utilize lateral connectivity, where survival of its juveniles is significantly higher than in main channels. Upon reaching about 2 years, juveniles return from backwaters to main channel. In some estuaries, it is also considered semi-anadromous due to juveniles frequently migrating to brackish waters to forage.			

7. Case study

7.1 Description of existing barriers in the Middle Danube

On the Slovak-Hungarian section of the Danube, the **Gabčíkovo Hydropower Plant (HPP)** has been built since 1992, which also includes structures in the original Danube channel as well as in the bypass canal (headwater and tailwater canal). The purpose of the hydroelectric structure is flood protection of the surrounding area, provision of navigation conditions for the international navigation route, power generation, recreation and sport.

Upstream of Gabčíkovo village the **Water Structure (WS)** was built. The water level difference is 8.30 metres at rkm 1851.75. This impoundment was built as a substitute stage on the Slovak territory instead of the original rising stage of the Dunakiliti hydroelectric power station (Fig. 3). The purpose of the Čunovo WS is to maintain the operating water level in the reservoir, to divide the flows between the bypass canal and the original riverbed channel of the Danube River, and to release sediments and ice into the original riverbed channel. The water stage consists of three weirs for the transfer of flood flows (the weir on the bypass, the Middle weir and the weir in the inundation), the Čunovo HPP, the lock, the intake into the Mosoni Danube and the sports complex “Divoká voda”. During annual mean flow conditions, the Čunovo HPP operates with controlled flow of 250-400 m3/s in the non-vegetative autumn-winter months and a flow of 400-600 m3/s in the vegetative spring-summer months. The flow is mainly transferred through the hydropower plant Čunovo I, which has a capacity of 400 m3/s. A new hydroelectric power station, Čunovo II, is planned to be built next to it, which will use the remaining summer flow of 200 m3/s. This means that the annual main water flow will be concentrated and therefore it will attract migrating fish under the common outlet of both power plants. In the summer period during the day, part of the flow of 10-15 m3/s is passed through the wild water raceways in “Divoká voda” sports complex, which will also attract a significant number of fish with the flow of water. The raceways have steps and waterfalls over 1.50 metres high, making them impassable for fish.

Fig. 3: Čunovo and Dunakiliti water structures

At river kilometre 1843.00, a transversal weir was built across the entire Danube riverbed to raise the water level in order to supply the right-side arm system on Hungarian territory. In the bend of the Danube in the Hungarian territory, at approximately river kilometre 1842, the original Dunakiliti dam was built to maintain the operating level in the reservoir and to distribute the flows. At present it maintains a level difference of 7.50 metres. 90% of the flow in total is released through the Dunakiliti weir and 10% of the flow is released into the old Danube channel through the transversal weir. As a result, some fish are also found below the transversal weir, which is an impassable barrier under normal conditions, but the main flow of water attracts migrating fish below the Dunakiliti impoundment, which is also an impassable barrier without a fish passage. Therefore, the whole section above these objects is considered unreachable for fish species under normal flow conditions.

A 32 km long bypass canal with a large hydroelectric power plant at Gabcikovo HPP and locks for large cargo ships has been built around the section of the Danube between 1851.75 and 1810.00 river kilometre. The locks enable the ships to overcome the height difference between the inlet and outlet channel ranging from 16 to 23.3 metres. Normally 80% of the total flow of the Danube in the range of 750 - 4500 m3/s is flowing through the bypass canal l (Fig. 4). The dominant flow of water through the bypass channel attracts migrating fish in the Danube below the Gabčíkovo HPP, where they remain because they have no possibility to cross the barrier. The outlet of bypass channel to the Danube is at river kilometre 1810 near the Sap village.

Fig.4: Gabčíkovo HPP, bypass – canal and Danube branch system

7.2 Design of target fish species and derived parameters of fish passes

In the Danube section of interest, there are about 80-100 fish species with different specificities and requirements for migration and living conditions. Many unique migratory fish species have already become extinct in this section or cannot migrate to their original spawning grounds because of the impassable barriers constructed in the lower section of the Danube by the Iron Gate I and II hydroelectric dams. Austrian and Slovak ichthyologists are carrying out programmes to restore the original spawning grounds of these rare species of fish, such as the Beluga sturgeon (Huso huso), which grow up in the Black Sea and subsequently go to spawn in the Danube arms in our territory. The Slovak ichthyologists request as the umbrella species - the Beluga sturgeon (Huso huso) - with a length of 4 metres to be chosen for the design of the fish passes on the main barriers. This species of sturgeon is found only at great depths in the stream, which is why a minimum depth of 2.50 metres and a surface width of 10-15 metres are required in the fish passes (technical pool-type or bypass bio-corridor). The conditions of a maximum permissible jump velocity of 1.40 m/s in the slot of the fish pass, or 1.30 m/s average velocity in a barrier-free by-stream bio-corridor, have been taken from foreign documents. These parameters result in very broad requirements for the dimensions, lengths and spatial location of the proposed fish passes.

7.3 Design of the fish pass at the Čunovo HPP

Due to the location of the existing and proposed hydroelectric power plant of the Čunovo I and II in the middle part of the stage, the conditions for the design of a large fish pass meeting the parameters for the design fish species are considerably cramped. The only possible open space near the water flow in the stream that will attract fish is the island between the hydroelectric power plant and the weir in the inundation.

On that island, it is spatially feasible to accommodate a technical slot-and-chamber fish pass of 1100 metres in length, which would consist of 92 pools (Fi. 5). The difference in level between the pools would be between 9 and 10 cm, which would ensure velocities in the slot of up to 1,40 m/s. The length of the pools would be 12 metres due to the requirement of 3 times the length of the fish. The width of the pools is 9 metres and the water depth is 2.50 metres.

Fig.5: Čunovo HPP – technical slot-and-chamber fish pass

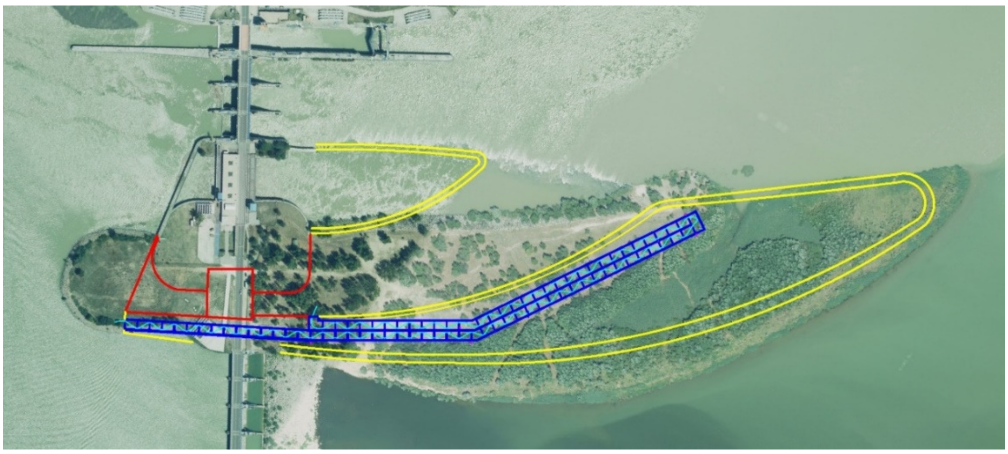
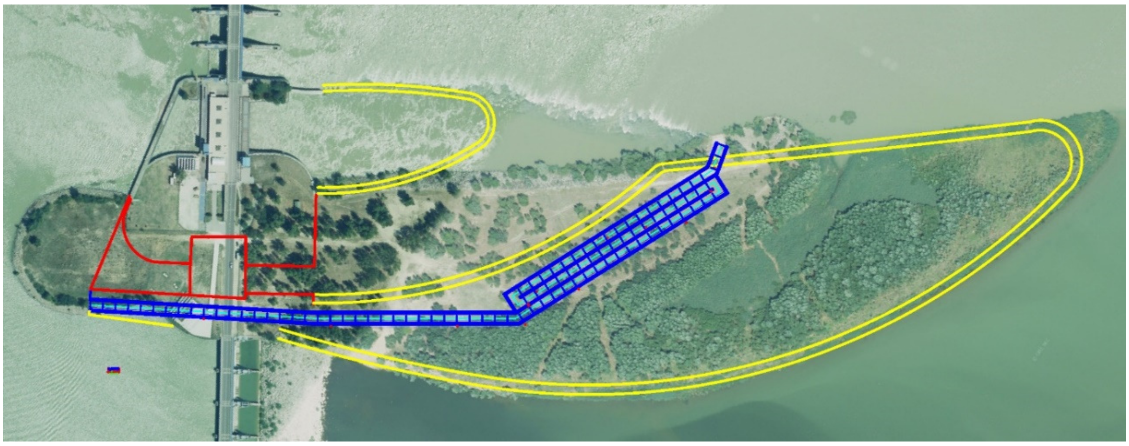


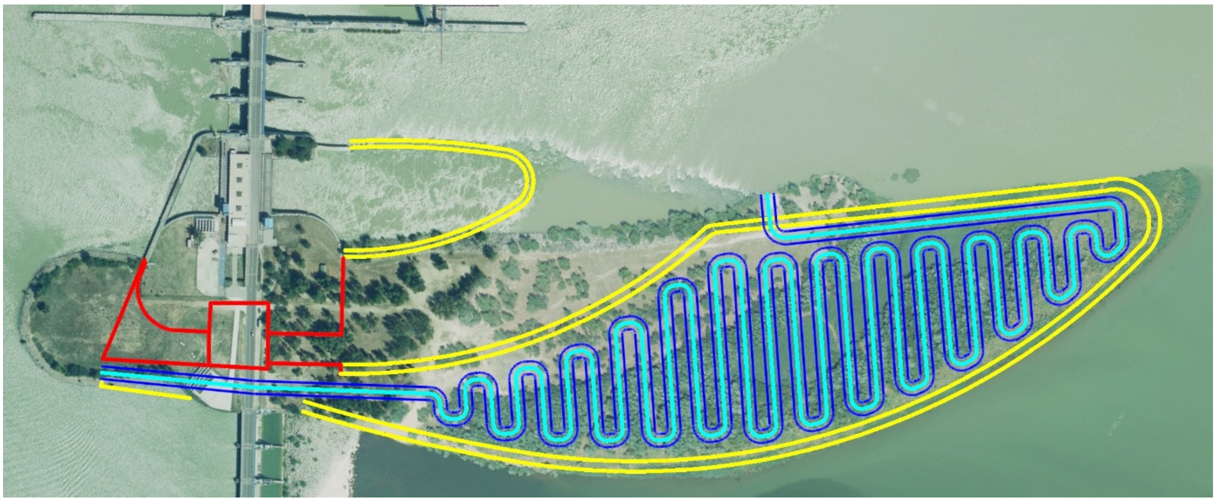
Fig.6: Čunovo HPP – two-slot design of the fish pass



A two-slot design is being considered, where a large 1.20 m wide slot would be in the deep part for sturgeons and a narrow 0.80 m wide slot would be in the shallow part of the pool with a depth of about 1.1 m suitable for the migration of smaller fish species such as barbel, nase, etc. A single slot design with a slot width of 2.0 m is also considered. The flow through the fish pass would be 5.0 m3/s or 8.4 m3/s depending on the type of design. The outlet of the fish pass would be at the end of the outflow canal from the two hydropower stations where the water flow is concentrated (Fig. 6).

Considering a nature bypass bio-corridor with the required parameters of 2.50 m depth and 10-15 m width at the surface, and at the same time very moderate average water velocities of up to 1.30 m/s, the design calculations result in extremely long bio-corridor lengths of approximately 6148 m. Such a bio-corridor cannot be placed on a dedicated island for structural and spatial reasons. Unfortunately, the island cannot be enlarged above or below due to possible restrictions of flow capacities of flood gates.

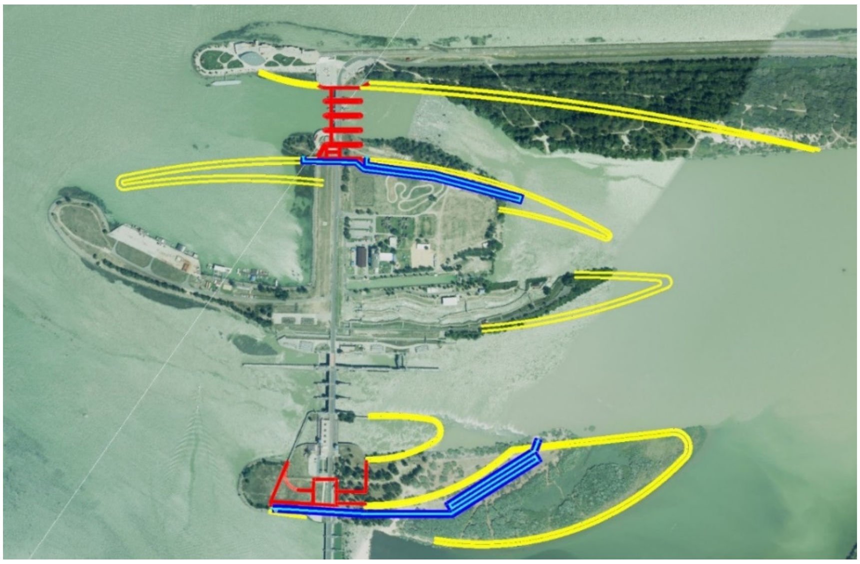
Fig. 7: Čunovo HPP – natural bio-corridor fish pass



A natural bio-corridor with a maximum depth of 1.50 m and a width of 10 m, with a total length of 3318 m, could be placed on the dedicated island, providing an average speed of 1.30 m/s suitable for virtually all migratory fish to cross (Fig. 7). Assuming a lower design depth or width, it would also be possible to design a bio-corridor with enlarged resting ponds for migratory fish. The appropriate design will be subject to hydraulic modelling and consultation with experts.

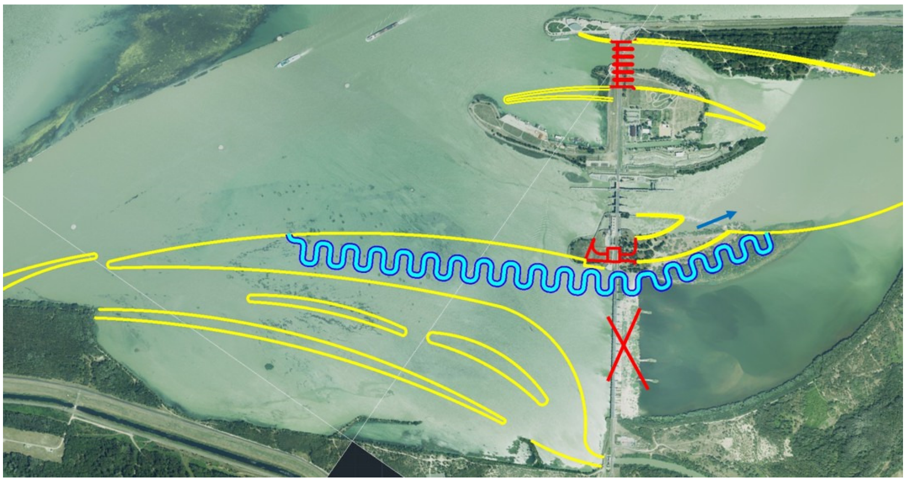
At the Čunovo stage where the outlet of the "Divoka voda" sports complex and the harbour bypass exit, a second additional fish pass is being considered to be constructed later, but with parameters only for smaller migratory fish (barbel, nase). The flow in fish pass would be only 1.0 m3/s and the depth in the fish pass would be up to 1.0 m (Fig. 8). Here it is possible to place both a technical and a bypass fish passes. The design of this fish pass should take into account a comprehensive rebuilding of the impoundment objects - rebuilding the bypass weir or removing the weir in the inundation - in order to improve the transport of flood flows and sediments through the stage.

Fig. 8: Čunovo HPP – technical and bypass fish passes



A number of experts do not recommend the construction of a technical fish pass with narrow slots for sturgeons, because they fear that the fish are afraid to enter confined spaces and they occur only in wide streams. Therefore, in case it is required to construct a "natural" bypass bio-corridor without barriers for sturgeon migration, it would be necessary to rebuild the strategic flood gates at the Čunovo HPP significantly in order to gain sufficient space. Moreover, the weir in inundation with a capacity of 5500 m3/s should be removed and adequate capacity weir to carry flood flows should be built at the location of the bypass weir, i.e. also to replace the existing small bypass weir. The new flood storage weir must have a capacity of 6600 m3/s. The space gained by replacing the weir in inundation would be sufficient to construct a natural bypass fish pass of at least 8200 m in length to provide the required depth of 2.50 m and velocities of 1.30 m3/s suitable for large sturgeon as well as other migratory fish species (Fig. 9).

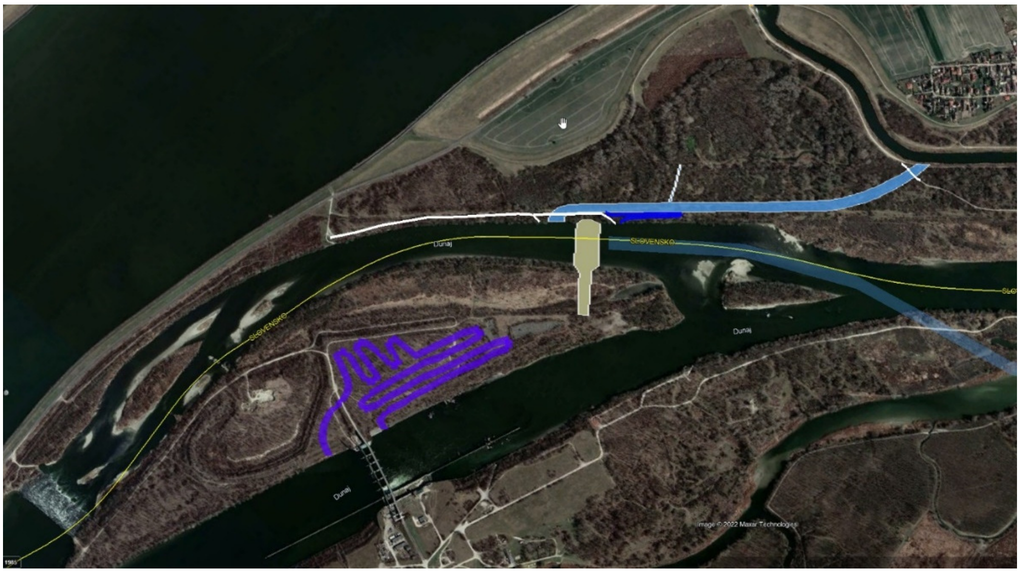
Fig. 9: Čunovo HPP – rebuilding flood gates and design of natural bypass bio-corridor fish pass



7.4 Design of the fish pass at the Dunakiliti HPP and the transversal weir

The Dobrohošt' site has a bottom =transversal weir at 1843 river kilometre and the Dunakiliti Bypass weir is built in the Hungarian territory in the archway. Both of these objects create an impassable barrier for migratory fish in the Danube. The migration barrier of the Dunakiliti weir can be overcome by constructing a technical or bypass fish pass on the island between the weir and the Danube bed where sufficient space is available. Unfortunately, it would be problematic to build a fish pass overcoming the current transversal weir in the Danube on the left or right side due to lack of space. The idea of the water managers from the Slovak Water Management Enterprise is to move the dewatering transversal weir 2 km downstream, which could create a water intake into the Slovak left-hand side of the river branch system and also to create a space for building a fish pass overcoming the new dam (Fig. 10). Such a solution would require an agreement with the Hungarian side.

Fig. 10: Design of the Dunakiliti fish pass



7.5 Design of the fish pass to the Gabčíkovo HPP

The Gabčíkovo hydroelectric power plant is built on the bypass canal. It uses 80% of the Danube's annual mean flow for energy, so the main water flow attracts most of the migrating fish below this barrier. The fish could pass above the Gabčíkovo hydropower plant by the = headwater canal through a fish pass with an elevation of 21.50 metres - technical fish pass or bio-corridor. The technical chamber fish pass would contain 210 pools with a level difference of 0.10 metres and a flow rate of 5.0 m^3/s (Fig. 11 and 12). Referring to these conditions, it would be possible to build a bio-corridor with a depth of 1.2 metres and a length of 6444 metres.

Fig. 11: Gabčíkovo HPP – design of the technical fish pass 1

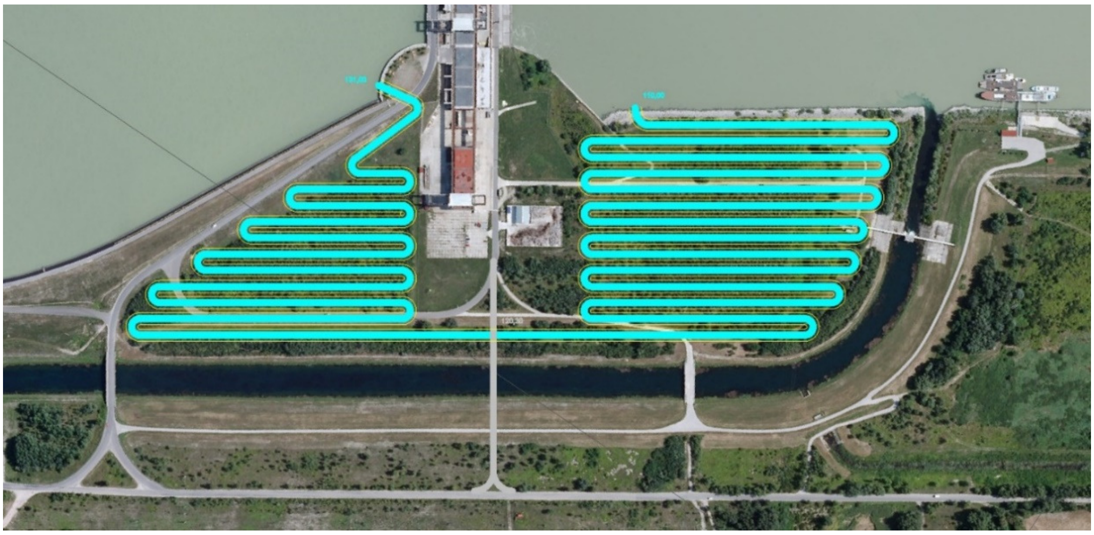
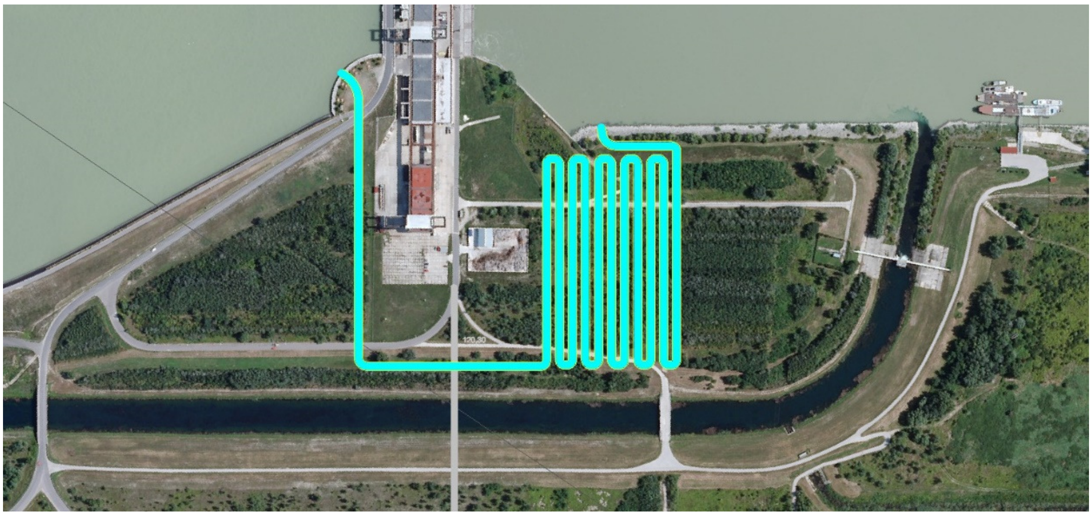


Fig. 12: Gabčíkovo HPP – design of the technical fish pass 2



Other option is to divert the fish towards the Danube river branch system, where the water level elevation is approximately 1.20 metres above the outflow canal channel (Fig. 13). This would result in one third of the flow of the branch system flowing under the hydropower plant and two thirds of the flow is flowing into the old Danube channel. The length of the realignment of the branch system and the bio-corridor would be 1570 metres. In this case, the flood protection barriers would have to be built on the sides of the section to prevent flooding of inhabited areas. This option seems to be feasible.

Fig. 13: Gabčíkovo HPP – fish pass through Danube River branch system

8. Next steps

Although much work has already been done to investigate the most efficient ways to overcome the man-made barriers in the rivers, there is still many challenges to be investigated and solved. Simultaneously, the designing and building the fish pass in Iron Gates I and II requires the harmonisation of the works in Gabcikovo Water Structure.

The future challenges and follow up activities relate to the biological issues, technical design, construction possibilities as well as promotion of the topic among relevant stakeholders and public:

- **Need for suitable methods to be selected and adopted jointly for target species with respect to different lifetime** (need to monitor both larvae and adult individuals). Monitoring adults can provide us with information about population structure and help us identify habitats and migration routes. This information can prove rather useful when considering designing and placement of fish pass. More research should be conducted on identification of key habitats, especially in case of sturgeons to ensure that these key habitats will be sufficiently protected. This is especially important because sturgeons used to share these habitats in the past.
- **Detailed site-specific research is needed at international level to specify the technical parameters and reliability of fish passes capacity for various migratory fish species, including sturgeons.** After evaluation of data from monitored existing fish passes for various species of migratory fish, including sturgeons, it will be possible to confirm or adjust the technical parameters for fish pass design in our area of interest at the Danube River.
- **Organize a workshop for Slovak and Hungarian experts to provide them with the updated technical solutions for fish passes construction in according to new guidelines**. The workshop (most probably in 2023) has been offered to be supported by presentation of Mr. Marq Redeker, CDM Smith, who is involved in Iron gates investigation through WePass I and II projects.
- **Search for synergies of WePass I and II projects and Gabčíkovo fish pass construction** (e.g. adapt methods of investigation in Iron Gates to search for the most proper place for fish pass location to be attractive for fish, i.e. effective for passing).
- **Plan to build the fish pass in Čunovo II HPP** within the new block of hydropower plant, which is planned in the near future by Water Construction enterprise.
- **Prepare a study on technical design of Danube sturgeon fish pass at Čunovo and Dunakiliti impoundments, and Gabčíkovo HPP based on mathematical modelling** (2026). The study will be prepared within the LIFE project "Implementation of the river basin management plan in selected river sub-basins in Slovakia", acronym: LIFE21-IPE-SK-LIFE Living Rivers.
- **Prepare a study on re-establishment of migration routes for sturgeon species on the Danube River and reconnection of its floodplain habitats** (2027). The study will be prepared

within the LIFE project “Implementation of the river basin management plan in selected river sub-basins in Slovakia”, acronym: LIFE21-IPE-SK-LIFE Living Rivers.

- **Prolong EUSDR PA4 fish migration activities –** planned to organise Fish migration conservation workshop in cooperation with PA6 (2024) and working meeting on fish migration conservation update under EUSDR Pillar 2 (PA4, PA and PA6) in 2027
- **Support new project ideas and ongoing project focused on fish migration restoration by EUSDR PA4**
- **Promote the topic on fish migration restoration among relevant stakeholders, public and youth** in cooperation with international organisations, e.g. International Commission for the Protection of the Danube Region (ICPDR), Global Water Partnership Central Eastern Europe (GWP CEE), World Wildlife Fund (WWF), etc.

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