Appendix H

LITERATURE OVERVIEW OF STURGEON MIGRATION BEHAVIOUR AND ANALYSES OF CURRENT LEGISLATIVE FRAMEWORK IN RELEVANT ICPDR COUNTRIES INCLUDING MULTILATERAL ENVIRONMENTAL AGREEMENTS WITHIN THE SCOPE OF WE PASS

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FOREWORD

This report has been prepared as part of Task 2 of the DG REGIO Grant, "Support for the Implementation of the Feasibility Study analysing options for fish migration at Iron Gate I & II" (WePass).

The necessity to secure viable populations of Danube sturgeons by restoring their habitats and migratory movements has been identified by the "Action Plan for the conservation of sturgeons in the Danube River" and in accordance with the EU Water Framework Directive, required steps included in the "Danube River Basin Management Plan". According to the Fishfriendly Innovative Technologies for Hydropower (FIThydro) project, sturgeon is classified in the group of 18 fish species of "highest sensitivity" (species under very high-risk during hydropower operation) among 148 native European fish and lamprey species.

According to international, regional, and national legislation, sturgeon are listed as critically endangered with a need to work on the recovery of their populations. This report carried out analyses of current legislation concerning sturgeon protection at different levels, with the main focus on regional and national legislation in four countries that belong to the Lower Danube Region (Romania, Bulgaria, Ukraine and Serbia) as well as in countries that belong to the Middle Danube Region (Croatia, Hungary, Slovakia). The survey of global instruments, global management support systems, regional instruments and European community laws and regulations was mainly based on the Pan-European Action Plan for sturgeon, whereas the survey of the national legislation was based on contacts with experts from Romania, Bulgaria, Ukraine and Serbia.

The main aim of this report is to summarize the experience on fish passage facilities designed for/ used by sturgeon and the criteria for effective passage of sturgeon, to understand the constraints on passing sturgeons and other migratory species at the Iron Gate I and II dams that include both upstream and downstream migration, as well as to help in finding a viable solution for migratory fish passage at these dams. To support this aim, this report is to provide a brief survey on the efficiency of fish pass use by sturgeon in Russia, the USA and Canada in view of the lack of such experience in Europe. The survey of fish pass efficiency in Russia included all existing constructions, while the survey of fish pass in the USA and Canada was based on an extensive

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literature search and contacts with relevant experts, including almost all structures where the efficiency of fish passage was examined.

List of abbreviations

BSSMAG	Black Sea Sturgeon Management Action Group
CBD	Convention on Biodiversity
CITES	Convention on International Trade in Endangered Species
CMS	Convention of Migratory Species
ICPDR	International Commission for the Protection of the Danube River
EUSDR	EU strategy for the Danube Region
FAO	United Nations Food and Agriculture Organisation
LDR	Lower Danube Region
PIT	Passive integrated transponder
RAMSAR	Convention on Wetlands of International Importance especially as Waterfowl Habitat
SAP	Sturgeon Action Plan
WFD	Water Framework Directive

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Definition of terms

Anadromous - fish species that travel upstream to spawn in freshwater (NMFS 2008).

Attraction flow - the flow that emanates from a fishway entrance with sufficient velocity and in sufficient quantity and location to attract upstream migrants into the fishway. Attraction flow consists of gravity flow from the fish ladder, plus any auxiliary water system flow added at points within the lower fish ladder (NMFS 2008).

Auxiliary water system - a hydraulic system that augments fish ladder flow at various points in the upstream passage facility. Typically, large amounts of auxiliary water flow are added in the fishway entrance pool in order to increase the attraction of the fishway entrance (NMFS 2008).

Burst swimming - Rapid movements of short duration and high speed, maintained for less than 15 sec. Energy is made available largely through anaerobic processes. Burst activity may be subdivided into an acceleration period and a sprint when swimming speed is high but steady (Beamish 1978).

Collection gallery – a fishway entrance channel that is installed perpendicular to the outflow on the downstream side of a hydropower plant. In the context of this report the expression "collection gallery" is used for the fishway entrance channel that is also commonly referred as "holding pool".

Critical swimming speed (U_{crit}) - The critical swimming speed is computed from the maximum speed achieved prior to fatigue (Beamish 1978). In order to measure U_{crit}, fish are subjected to stepwise increases in swimming speed (usually in a water tunnel) until fatigue occurs.

Fatigue - A fish is fatigued when it collapses and can longer maintain a given swimming speed (Beamish 1978).

Fish ladder - the structural component of an upstream passage facility that dissipates the potential energy into discrete pools, or uniformly dissipates energy with a single baffled chute placed between an entrance pool and an exit pool or with a series of baffled chutes and resting pools (NMFS 2008).

Fish lift - a mechanical component of an upstream passage system that provides fish passage by lifting fish in a water-filled hopper or other lifting device into a conveyance structure that delivers upstream migrants past the impediment (NMFS 2008).

Fish lock - a mechanical and hydraulic component of an upstream passage system that provides fish passage by attracting or crowding fish into the lock chamber, activating a closure device to prevent fish from escaping, introducing flow into the enclosed lock, and raising the water surface to forebay level, and then opening a gate to allow the fish to exit (NMFS 2008).

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Fishway - the set of facilities, structures, devices, measures, and project operations that together constitute, and are essential to the success of, an upstream or downstream fish passage system (NMFS 2008).

Fishway entrance - the component of an upstream passage facility that discharges attraction flow into the tailrace, where upstream migrating fish enter (and flow exits) the fishway (NMFS 2008).

Fishway exit - the component of an upstream passage facility where flow from the forebay enters the fishway, and where fish exit into the forebay upstream of the passage impediment (MNFS 2008).

Forebay - the waterbody impounded immediately upstream of a dam (NMFS 2008).

Hopper - a device used to lift fish (in water) from a collection or holding area, for release upstream of the impediment (NMFS 2008).

Impingement - the consequence of a situation where flow velocity exceeds the swimming capability of a fish, creating injurious contact with a screen face or bar rack (NMFS 2008).

Large dam - According to the International Commission on Large Dams (ICOLD) a large dam is defined by:

- A height of 15m or more
- A height between 10 and 15m, if it meets at least one of the following conditions:
    - the crest length of the dam is not less than 500m
    - the spillway discharge potential exceeds 2,000m^3 per second
    - the reservoir volume is not less than 1 million m^3.

Prolonged swimming - Covers a spectrum of speeds between burst and sustained and is often categorized by steady swimming with more vigorous efforts periodically. The swimming period lasts between 15 sec and 200 min and if maintained will end in fatigue. Energy is supplied from either or both aerobic and anaerobic processes (Beamish 1978).

Sustained swimming - A spectrum of swimming activities and speeds that can be maintained for an indefinite period (in operational terms for longer than 200 min) and does not involve fatigue. Metabolism is aerobic and the activities would include foraging, station holding, schooling, cruising at preferred speeds in negatively buoyant fish, and steady swimming at low speeds, including migration (Beamish 1978).

Tailrace - the stream immediately downstream of an instream structure (NMFS 2008).

Thalweg - the stream flow path following the deepest parts of a stream channel (NMFS 2008).

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Threshold current velocity – The minimum current velocity which leads to an orientation reaction against current (Pavlov 1989).

Trap and Haul - a fish passage facility designed to trap fish for upstream or downstream transport to continue their migration (NMFS 2008).

Upstream fish passage - fish passage relating to upstream migration of adult and/or juvenile fish (NMFS 2008).

Upstream passage facility - a fishway system designed to pass fish upstream of a passage impediment, either by volitional passage or non-volitional passage (NMFS 2008).

Weir - an obstruction over which water flows (NMFS 2008).

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1. INTRODUCTION

The construction of dams blocked sturgeon migration and decreased available spawning and early life-phase habitats throughout their range. Additionally, the modification of riverbeds for navigation purposes, increased pollution and overfishing as well as poaching, which exerted a negative impact on sturgeons, rendering most of them endangered or critically endangered (IUCN 2010). Consequently, they are considered as a target species for remediation measures, including the construction of fish passages.

A fish passage facility represents a device to facilitate fish passage over or around an obstacle. The first fish passes were created mainly for salmonids, which have strong swimming capabilities, and for clupeids, which are generally pelagic. In contrast, sturgeons are bottom-oriented species with a swimming performance which is lower than in salmonids (McElroy et al. 2012).

Provision of upstream and downstream sturgeon passage is a significant challenge as knowledge on sturgeon passing upstream is limited, whereas knowledge of sturgeon passing downstream is practically non-existent (Wittmann-Todd et al. 2003). The design of a successful fish passage facilities for sturgeon for upstream and downstream sturgeon migration is still in an experimental phase. There are some lessons learned and particular success in this topic provides hope for reconnecting fragmented sturgeon populations (Jager et al. 2016, Katopodis and Williams 2012).

While there are 863 km of the Danube River in the Lower Danube Region (LDR) available for largely unobstructed migration of the three remaining anadromous sturgeons: beluga (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedtii*) and stellate sturgeon (*Acipenser stellatus*) and their potamodromous relative the sterlet (*A. ruthenus*), construction of fish passages on Iron Gate I at 863 rkm and Iron Gate II at 943 rkm could open an additional 900 km for migration up to the Gabcikovo dam at rkm 1,816. This reconnection would enable the sturgeon to reach the majority of their historical spawning habitats.

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2. LEGISLATIVE FRAMEWORK IN RELEVANT ICPDR COUNTRIES CONCERNING STURGEON STATUS

Sturgeons are migratory fish species, and the life cycle of many species includes the utilization of marine and coastal waters as well as riverine ecosystems. In many cases these regions represent a border area between different range states. Therefore, the protection of migratory fish species calls for a common approach (Friedrich et al. 2018). The protection of sturgeon is addressed in international, regional, and national legislations. A legislative framework for the protection of sturgeon populations does not only exist in EU member states but also in non-EU countries (Friedrich et al. 2018). The protection of sturgeon species in the ICPDR (International Commission for the Protection of the Danube River) countries is the result of national legislation. National legislation in turn is mainly based on international agreements, among which are the most important conventions, such as the Convention on International Trade in Endangered Species (CITES), the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), the Convention of Migratory Species (CMS, Bonn Convention), and the Convention on Wetlands of International Importance (Ramsar Convention). In the EU, the legislative framework is the implementation of the Flora-Fauna-Habitat Directive (FFH).

2.1. International instruments

Relevant global instruments, global management support systems, regional instruments and European community laws and regulations are presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** in accordance with the Pan-European Action Plan for Sturgeons (Friedrich et al. 2018).

Table 1: Global instruments, global management support systems, regional instruments, and EU laws with implications for the protection and management of sturgeons

Global instruments
The Convention on Biodiversity (CBD) – Strategic plan 2011-2020
The Convention of Migratory Species (CMS, Bonn Convention, 1979)
The Convention on International Trade in Endangered Species (CITES, Washington, 1973)
The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention, 1971)
Global Management support systems
The United Nations Food and Agriculture Organisation (FAO)
Regional instruments
The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention)
The Convention on the Protection of the Black Sea against Pollution (Bucharest Convention)
The Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention)
European Community laws and regulations

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European Directive on the Protection of Flora, Fauna and Habitats – Habitats Directive (92/43/EEC)
EU Water Framework Directive (WFD) (Directive No. 2000/60/EC of 23 October 2000)
The EU strategy for the Danube Region (EUSDR)

The Pan-European Action Plan for Sturgeons (Friedrich et al. 2018) gives detailed explanation for the protection and management of sturgeons as defined in relevant EU documents. Implementation of the legal framework (EU Habitats Directive, RAMSAR, and Biological Diversity) is necessary for improvement of sturgeon status through the conservation of habitats. The EU Strategy for the Danube Region (EUSDR) in Priority area 4 (Water quality) and Priority area 6 (Biodiversity) mentions sturgeon conservation as a target.

2.2. National legislation

At the national level, strategies, programmes, and laws deal with the protection and management of sturgeons (**Fehler! Verweisquelle konnte nicht gefunden werden.**). In the Serbian National strategy for the sustainable use of natural goods and resources, the decrease in natural sturgeon populations is recorded as the consequence of anthropogenic impact (interruption of migratory pathways, deterioration of habitats, overfishing). According to the Strategy for water management on the territory of the Republic of Serbia, support for longitudinal continuity by the building of fish passes has been proposed (Galambos 2018).

The National Strategy and the Action Plan for the Conservation of Biodiversity in Romania includes principles and objectives of the CBD. Romanian Fishing Law, Romanian National Strategy for Fishing Sector 2014-2020 and Operational Programme for Fishing and Maritime Affairs 2014-2020 are in line with EU regulations for fisheries and sustainable fishing and restoration of overexploited stocks.

The National Biodiversity Strategy of Bulgaria was the basis for the Biodiversity Act from 2002, and of the 2nd National Action Plan for Biodiversity Conservation for the period 2005-2010. Amendments to the Biodiversity Act (2002) have constantly been made to take into account European laws such as the Habitats Directive. Currently, the Biological Diversity Act has been updated according to the latest development in EU legislation and a new Biodiversity Strategy is under development.

In Ukraine, sturgeons are included in the Red Data Book of protected species, their capture requiring special permits for scientific and breeding purposes.

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Table 2: National strategies and laws for sturgeon protection and management in the LDR countries

Serbia	Reference	Relevance to sturgeon
National sustainable development strategy	Official Gazette No 57/2008	Possibility to overcome decrease in sturgeon natural populations by aquaculture development
National Environment Protection Programme	Official Gazette No 12/2010	Refer to Action plan for sturgeons in Serbia
Biodiversity strategy of the Republic of Serbia for the period 2011-2018	Official Gazette No 13/2011	Impact of Iron Gate I and II on sturgeon population
National strategy of sustainable usage of natural goods and resources	Official Gazette No 33/2012	Anthropogenic impact on sturgeon wild populations
Law on Nature Protection	Official Gazette No 14/2016	Status of sturgeon protection in Serbia
Law on protection and sustainable use of fish resources	Official Gazette No 128/2014	Permanent ban on catch of sturgeons in Serbia
Romania		
National Strategy and Action Plan for the Conservation of Biodiversity 2014-2020 (NSAPCB)	1081/2013	Negative impact of Iron Gate I and II on sturgeons All sturgeon species mentioned as included in the Red list of protected species
Romanian Fishing Law	Law 317/2009	Capturing, possessing, transporting, commercializing sturgeons without documents or legal justifications
Romanian National Strategy for Fishing Sector 2014-2020 (NSFS)		Sturgeons mentioned as protected species, whose capture is allowed only for scientific and aquaculture purpose
Operational Programme for Fishing and Maritime Affaires 2014-2020 (OPFMA)		Promote recirculation systems in aquaculture (including sturgeons)
Regime of nature protected areas, conservation of natural habitats, wildlife flora and fauna, modified and completed by Law 49/2011	OUG 57/2007	Status of sturgeon protection in Romania
Bulgaria		
Biological Diversity Act	State Gazette No 77/2002	Status of sturgeon protection in Bulgaria
2nd National Action Plan for Biodiviersity Conservation for the period 2005-2010	Ministry of Environment and Waters 2005	Establishment and maintenance of DNA databank for sturgeons
Bulgarian Operational Programme Environment 2014-2020		Water resources protection and biodiversity conservation
Bulgarian Fisheries and Aquaculture Act	State Gazette No 41/2001	Ban on sturgeon fishing
Bulgarian Water Act	State Gazette No 67/1999	Regulates water quality parameters for aquatic species including sturgeons

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Ukraine		
Red Data book of Ukraine. Animal World	2009	Status of sturgeon protection in Ukraine, ban on sturgeon catch except special permits for scientific and breeding purpose
Law on Environmental Protection of Ukraine	No. 1264-XII 25.06.1991	The importance of sturgeon protection and their habitats, and the legal principles for their use, protection and restocking
Law of Ukraine On the Fauna	No. 2894-III December 13, 2001	The general principles of Fauna conservation and protection, most rules of rare species use and protection (including sturgeons)
Law of Ukraine on Fishery, Commercial Fishery and Water Biodiversity Protection	No. 3677-VI 08.07.2011	Prohibition of fishing of "aquatic living resources/animals" listed in the Red Book of Ukraine

2.3. A historical perspective of harvest regulations and protection attempts

Sturgeons represent a natural and cultural heritages of the Danube River, which can be tracked from the Mesolithic and early Neolithic periods, based on archaeological data in the Danube Gorges Region (Zivaljevic 2012). Medieval documents and the construction of sturgeon traps in the nineteenth century in the Iron Gates Gorge corroborate their importance at that time (Bartosiewicz et al. 2008). Habitat modification and overfishing were the main reasons for the decrease of sturgeon populations in the Danube River, which can be reconstructed by the decrease of annual sturgeon catches, which were about 1,000 t at the start of the 20th century and dropped significantly by the end of the century (Vassilev 2006). In Romania sturgeon catch drooped from about 1,144 tons in 1940 to less than 8 tons in 1995 (Navodaru et al. 1999).

A "Convention concerning Fishing in the Waters of the Danube" was signed by Romania, Bulgaria, Yugoslavia and the Soviet Union in 1958. Regular meetings of this convention were organized until 2000 with the main aim of monitoring and regulating commercial fisheries, especially sturgeons and Pontic shad. The Convention coordinated scientific research in different countries and proposed common measures for the sustainable use of economically important migratory fish species. A ban on sturgeon fishing was declared from 15 March till 15 June, depending on the Danube River sector from the Black Sea to Kladovo (rkm 934), with a catch-size limit for sturgeons (length from the tip of the snout to the base of the tail fin for beluga sturgeon – 140 cm, Russian sturgeon – 80 cm, stellate sturgeon – 75 cm, and sterlet 33 cm), and a total ban for ship sturgeon. The Convention was not active after 2000.

In 1997 all sturgeon species were listed in Annex 2 of the Convention on International Trade in Endangered Species (CITES). This CITES listing was ratified by Bulgaria, Romania, Ukraine and Serbia in 1991, 1994, 1999 and 2001, respectively, requesting agreed upon quotas for shared sturgeon stock to be harvested. A general ban of commercial catch of all sturgeon species except for scientific and breeding purposes was declared in 2000 in Ukraine. Regular meetings of Lower Danube Countries (Romania, Bulgaria, Ukraine, and Serbia) were initiated in 2002, which harmonized CITES quotas for sturgeon catch in LDR. Meetings were organized with the regular

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participation of 2 experts of the CITES Secretariat Scientific Support Unit. The Black Sea Sturgeon Management Action Group (BSSMAG) was established at the Second Regional Meeting held in 2003 in Tulcea (Romania), and a "Regional Strategy for the conservation and sustainable management of sturgeon populations of the N-W Black Sea and Lower Danube River in accordance with CITES" was agreed between Ukraine, Romania, Bulgaria and Serbia (Anonymous 2003).

Negotiations within the framework of the CITES initiated activities on the development of national management and the action plan for sturgeons in LDR countries (Romania, Serbia, Bulgaria). The National Sturgeon Management Plan was developed in Romania (Anonymous 2004) to implement the Regional Strategy for Sturgeon, but currently there is no national SAP in Romania. The Sturgeon Action Plan (SAP) for Bulgarian territorial waters of the Danube and the Black Sea was issued by the Ministry of Environment and Water in 2004 (Zivkov et al. 2004). It is still binding, and its main challenges and deficiencies are due to the lack of detailed monitoring data. The "Action Plan for sturgeon species management in fishery waters of the Republic of Serbia" was completed in 2005 and is not legally binding even though a part of the Action plan was implemented through national and international projects (Lenhardt et al. 2005). The Action Plan for the conservation of sturgeons in the Danube River Basin was published under the Bern Convention (Bloesch et al. 2006). The Ukrainian SAP, which is based on the Pan-European Action Plan for Sturgeons, was adopted by the Ministry of Energy and Ecology in January 2021. After a period of 4 years of monitoring of essential sturgeon population indicators (age structure, juvenile production index) in Romania (Paraschiv et al. 2006), a 10-year moratorium on wild sturgeon fishing was enforced in 2006, which was followed by imposition of a sturgeon fishing ban in Serbia (for beluga, European sturgeon, *Acipenser sturio*, Russian sturgeon, stellate sturgeon and ship sturgeon, *Acipenser nudiventris*) in 2009 and in Bulgaria in 2011. The fishing ban in Romania was prolonged in 2016 for 5 years and is in force until 2021 in both Romania and Bulgaria. Bulgaria has announced its prolongation for an additional 5-year period as of 01.01.2021 and Romania published on 16 April 2021 the fishing ban prolongation order for an indefinite period until stocks have recovered. In 2017, bilateral agreements were signed between Romania and Bulgaria to harmonize/coordinate the implementation of the moratorium in the border area. In 2018, bilateral agreement was signed between Romania and Ukraine. From 1st January 2019 the Ministry of Environmental Protection of the Republic of Serbia prohibited the catch of sterlet.

At present, the national order issued by the Ministry of Agriculture in 2016 (Official Gazette, no. 303, 2016, Romania), countersigned by the Ministry of Environment, Water and Forests with regard to measures to restore and conserve sturgeon populations in natural habitats (**Fehler! Verweisquelle konnte nicht gefunden werden.**) is in force in Romania. In the order, ship sturgeon, Russian sturgeon, stellate sturgeon and beluga are listed as critically endangered, while sterlet is considered vulnerable.

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In Serbia, the Law on Nature Protection states that all sturgeons, except sterlet, are strictly protected wild species, while the Law on protection and sustainable use of fish resources affirms a permanent ban on the catch of all sturgeons. In Bulgaria, European and ship sturgeon have been listed in Annex 3 (protected for the entire territory of Bulgaria) of the Biological Diversity Act, while beluga, Russian and stellate sturgeon as well as sterlet are included in Annex 4 (regime of protection and regulated use in the wild) of the same act. The Red data book of Ukraine has listed Russian and stellate sturgeon as vulnerable species, beluga and sterlet as endangered species, while European and ship sturgeon are listed as critically endangered (vanished).

Legislation in Middle Danube countries supports river continuity, protection of key habitats and protection of sturgeons as the most endangered species. In Slovakia, the updated National Strategy for the Protection of Biodiversity to 2020 (issued by Slovak Republic in 2014) is connected to the WFD and the Slovak Water Plan, which state the need for continuity of waterbodies by facilitating migration at barriers. In accordance with National Strategy for the Protection of Biodiversity of Slovakia, appropriate measures need to be taken to secure wild fish stocks: restocking and protection of river habitats suitable for the reproduction of fish and the development of fry and young fish. Russian sturgeon is protected for the whole year and for sterlet a closed season exists from 15 March to 31 May every year in Slovakia.

Table 3: Status of sturgeons in Bulgaria, Romania, Serbia and Ukraine

Latin name / Common name	Nature protection[1]	Protection of fish resources[2]	Measures to restore sturgeons[3]	Red Data Book of Bulgaria[4]	Red Data Book of Ukraine[5]	Bern Convention[6]	Bonn Convention[7]	CITES[8]	EU habitats directive[9]	IUCN Red List[10]
Acipenser gueldenstaedtii / Russian sturgeon	SPWS	PBC	CR	CR	VU	Not listed	II	II	V	CR
Acipenser nudiventris / Ship sturgeon	SPWS	PBC	CR	EX	EX	Res. 6 new	II	II	V	CR
Acipenser ruthenus / Sterlet	PWS	PBC	VU	EN	EN	III	II	II	V	VU
Acipenser stellatus / Stellate sturgeon	SPWS	PBC	CR	CR	VU	III	II	II	V	CR
Acipenser sturio / European sturgeon	SPWS	PBC	CR	EX	EX	II Res. 6	I, II	I	II, IV	CR

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Huso huso / Beluga sturgeon	SPWS	PBC	CR	CR	EN	III	II	II	V	CR

[1]**Nature protection** – Code on declaration and protection of strictly protected and protected wild species of plants, animals and fungi, ("Official Gazette of Republic of Serbia", no. 5/2010, 47/2011, 32/2016 and 98/2016): **SPWS** – strictly protected wild species; **PWS** – protected wild species; [2]**Protection of fish resources** Order about measures for preservation and protection of fish resource ("Official Gazette of Republic of Serbia", no. 56/2015 и 94/2018): **PBC** – permanent ban on catch; **TBC** – temporary ban on catch; **MLC** – minimal length for catch; [3] **The measures to restore and conserve sturgeon populations in natural habitats** (the Official Gazette, no. 303, 20.04.2016, Romania): VU – Vulnerable, CR – Critically endangered; [4]**Red Data Book of Bulgaria (Golemansky 2011):** EN – Endangered, CR – Critically endangered, EX – extinct; [5]**Red Book of Ukraine (Akimov 2009)**: VU – Vulnerable, EN – Endangered, CR – Critically endangered; [6]**Bern Convention** – Appendix II - Strictly protected fauna species; Appendix III - Protected fauna species; Res. 6 (1998 – Resolution 6. Bern convention standing committee - species requiring specific habitat conservation measures), Res. 6 new (2011 – Revised Annex I of Resolution 6. Bern convention standing committee – new species requiring specific habitat conservation measures); [7]**Bonn Convention -** Appendix I – endangered migratory species; Appendix II - Migratory species conserved through Agreements; [8]**CITES** –Appendix **I** - species is threatened with extinction and CITES prohibits international trade in specimens of these species except when the purpose of the import is not commercial; Appendix **II** - species that are not necessarily now threatened with extinction but that may become so unless trade is closely controlled and species whose specimens in trade look like those of species listed for conservation reasons; [9]**The habitats directive** –Annex **II** – Animal and plant species of community interest whose conservation requires the designation of special areas of conservation; Annex **IV** Animal and plant species of community interest in need of strict protection; Annex **V** - Animal and plant species of community interest whose taking in the wild and exploitation may be subject to management measures; [10]**IUCN Red List** – VU – Vulnerable, CR – Critically endangered.

In the National Biodiversity Strategy of Hungary (2015-2020), measures that could improve the situation of migratory fish relate to the protection of spawning grounds and restocking to strengthen fish populations. Management activities to successfully reduce illegal catches are referred to in the strategy and include monitoring and the protection of the most endangered species. The conservation plan for sterlet was developed and published in 2016 with the main aim to protect and re-establish sterlet populations in the Hungarian Danube catchment. It also describes risk factors for the preservation of sterlet, such as fishing, habitat change, water quality degradation and weakening of genetic integrity. In Hungary all sturgeon fishing is banned, without an expiry date.

The Nature Protection Strategy and Action Plan of the Republic of Croatia refers to the preservation of unfragmented natural areas and restoration of the most-threatened and degraded habitats. According to the Croatian River Basin Management Plan (2016-2021), in waterbodies that lack good ecological status, the effect of hydro-morphological conditions on the state of fish populations has to be determined. In Croatia all sturgeon species, except sterlet, are enlisted as strictly protected species and fishing of sterlet is prohibited from 1 March to 31 May with a catch-size limit of min. 40 cm.

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2.4. Urgently needed measures

There are several problems that have contributed to the decline of wild sturgeon populations in the LDR and Black Sea Region, but two categories have been identified as major threats that have led to a significant decrease in the number of sturgeons approaching Iron Gates II:

1. Illegal fishery (poaching): despite the fact that sturgeon fishery is prohibited in all LDR countries, the black market flourished after the ban, resulting in a reduction in the number of adult sturgeons capable of spawning, thereby further weakening the wild populations, and
2. Habitat destruction has led to a significant loss of sturgeon spawning, nursery, feeding and wintering areas in the Danube River and its tributaries. Habitat fragmentation by hydropower dams, hydro-technical works to ameliorate navigation, and the decrease in Danube discharge during severe droughts play a key role in the decline of wild sturgeon populations.

As the states through which sturgeons pass are contracting parties to a series of internationally binding agreements, such as the Bern Convention, CBD and CMS, there is a legal foundation for an agreement on the joint protection of sturgeons in the LDR. An agreement dealing with common fishery resources in LDR countries, as well as a concerted transnational monitoring program of wild sturgeon populations is urgently needed. The most appropriate and effective framework for such an agreement needs to be taken into consideration.

The construction of the Iron Gates without fish passage highly impacted sturgeon populations by blocking river habitat access and degradation of populations. The hydroelectric dams induced restricted movements of anadromous sturgeons (beluga, Russian and stellate sturgeon) and reduced their distribution, numbers and genetic diversity. Dams may directly impact sturgeons by seasonal disruptions in habitat and indirectly by habitat degradation and loss. Concerning sterlet, isolation by dams could reduce the genetic diversity within impoundments. By opening the Iron Gates, an additional suitable spawning habitat would become available for sturgeons, which was mapped into the framework of the MEASURES (Managing and restoring aquatic EcologicAl corridors for migratory fiSh species in the danUbe RivEr baSin) project on the sector of the Danube River from Iron Gate I to Gabcikovo dam based on data for sterlet. Investigation in the frame of MEASURES project confirmed existence of wintering, spawning, nursery and feeding habitats in sectors of the Danube River upstream of Iron Gate I till Gabcikovo dam as well as in the Danube River tributaries which probably could be appropriate for other sturgeon species in case the Iron Gates opening.

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3 FISH PASSAGE CONCEPTS

The construction of dams on rivers has had a high impact on migratory fish species, causing the fragmentation of riverine habitats. There are approximately 900,000 dams globally, 45,000 of which are large dams (WCD 2000), which are primarily for hydropower production and flood control. The construction of fish passes on dams represents alternative mechanisms aimed at facilitating the passage of migratory fish species. Effective fish passes could allow upstream and downstream fish movement.

3.1 Facilities for upstream and downstream migration and assessment of their efficiency

Fish passes for upstream migrating adult fish can be classified into two types of passes: fish locks or elevators and fishways. Locks and elevators actively move fish over an obstruction, while fishways require the fish to actively move through a bypass that helps to overcome a barrier (Noonan et al. 2012). Fishways include nature-like bypass channels and technical fish passes. Additionally, guidance systems are needed to attract sturgeons to upstream as well as downstream fish passes, regardless of the fish passage facility (Jager et al. 2016). Apart from guidance systems, downstream migration includes facilities for downstream migration and fish protection (Schmutz and Mielach 2013). There are two types of fish protection facilities: physical barriers (inclined bar racks, wedge wire screens, drum screens, etc.) and non-physical/behavioural barriers (electricity, light, sounds, air bubbles etc.). Fish protection facilities and guidance systems require a bypass system to circumvent the downstream migration obstacle. Downstream migrating fish can also pass through operating turbines, open spill gates and navigation locks if these facilities are designed appropriately. The passage of fish through turbines is restricted by fish size, the height difference of up- and downstream water levels, the rotation speed of the turbine, the number and shape of the rotors which all affect the intensity of fish injury and mortality. Depending upon precautionary measures some turbines exhibit reduced damage to fish (Schmutz and Mielach 2013).

Knowledge of the life history of a fish species, behavioural attraction to the entrance of a fishway, and detailed knowledge of swimming performance are needed for successful fish-passage facilities (Lucas and Baras 2001). Methods to investigate the swimming performance of fish can be laboratory- and field-based (Katopodis et al. 2019). To determine swimming ability (i.e., sustained, prolonged, burst swimming speeds, critical swimming speeds), laboratory investigations use test flumes. The main drivers for swimming performance are related to fish species and its size (Katopodis and Gervais 2016). However, no laboratory-based method can generate hydraulic conditions, such as highly variable turbulence and velocity distribution found in actual fishways, and this represents a challenge for the design of upstream and downstream fishways based on swimming performance data obtained from experiments (Katopodis et al. 2019). Therefore, it is very important to test the data obtained under laboratory conditions in the field, verify the performance of fish migration assisting structures and optimize them in situ.

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Field studies mainly include telemetry investigations and underwater video cameras (Thiem et al. 2011).

Data about fish behaviour and swimming performance are required as criteria for designing the fish attraction, guidance and layout of a fish pass (Peake et al. 1997, Katopodis 2005). An efficient fish pass should enable fish to pass with minimum delay, stress and injury. There is a need to optimize three processes to expedite fish passage (Castro-Santos 2011). Fish must approach and locate the zone of fish passage, the 'Approach zone', and enter the fishway at the 'Entry zone', to ascend or descend through the fishway via the 'Passage zone', and to exit the fishway safely (Figure 1, Castro-Santos 2011). The assessment of the efficiency of a fishway therefore includes the determination of attraction efficiency, passage efficiency and a secure fish exit. The efficiency is determined as the proportion of individuals in the downstream dam area that are subsequently located at the fishway entrance; passage efficiency is defined as the proportion of successfully passed individuals. Concerning fish attraction, it is very important to have a sufficient flow volume and velocity, but the direction of the attraction flow (diagonal water discharge to the main flow is preferable) and its location in relation to the current below the dam is of utmost importance too.

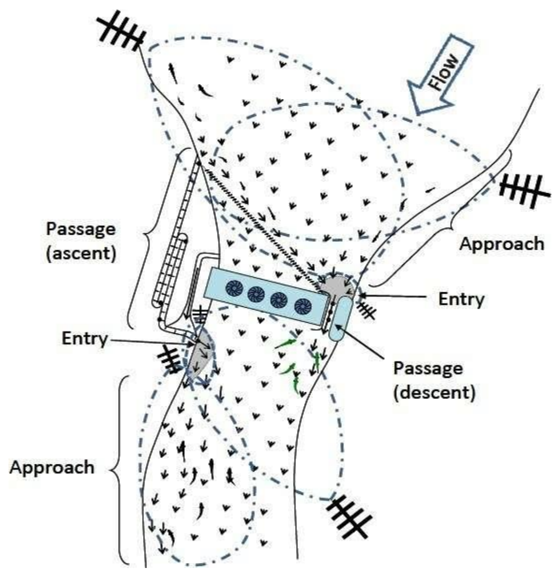

Figure 1: Schematic presentation of bi-directional fishways with the 'Approach zone', 'Entry zone' (shaded areas) and 'Passage zone'; the arrows indicate the flow vectors (length corresponds to velocity). Antenna arrays presented as the potential to monitor by radio telemetry when fish enter or exit a particular zone (Castro-Santos 2011)

Determination of fishway performance can also be based on the proportion of fish that effectively cross an obstacle and the delay that they experience between arrival and passage. In cases where fish must pass multiple dams to reach a specific spawning habitat, these criteria

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could be satisfied for all except the first fishway, because the duration of contact at the first dam is not possible to estimate (Castro-Santos 2011). In such case radio and acoustic telemetry allows receivers to detect a fish as they approach and pass fishway, so it offers appropriate set of tools for fish evaluations (Castro-Santos 2011).

Designing an efficient fish passage that causes minimal delay and post-passage impact requires a collaborative approach to create the best solution for a specific site as well as adaptive management and constant improvement.

3.2 Knowledge about sturgeon swimming performance and use of fish pass

Upstream passage facilities with large entrances, full-depth guidance systems, large lifts or a wide fishway without a tight turns or obstructions, as well as nature-like fishways, large canal bypasses and bottom-draw sluice gates for downstream passage have been successful solutions for sturgeons (Jager et al. 2016). A nature-like fishway (large canal bypass) on the Holyoke Dam and bottom-draw sluice gates on the Slave Falls Dam are the best examples of sturgeon downstream passage (Jager et al. 2016).

Many fish passages were constructed for salmonid fish, which are better swimmers than other fish species. There is a lack of information about the ability of sturgeon to evaluate the combination of flow depth, velocity, and turbulence (Cheong et al. 2006). Field studies have revealed a preference of pallid sturgeon to river sectors with the lowest water velocities as energy-inexpensive routes (McElroy et al. .2012). Sturgeons showed poor swimming performance relative to salmonids in all categories of swimming: sustained swimming, prolonged, and particularly, burst swimming (Peake et al. 1997). The heterocercal tail of sturgeon develops 18% less thrust at sustained and prolonged speeds in comparison with trout of comparable size (Webb 1986), and the sturgeon body surface with external scuta produces a 3.5-times higher drag in comparison to similar-sized trout. Bearing this in mind, as well as poor burst swimming endurance (Peake et al. 1997, Cheong et al. 2006), a ladder design that allows slower speed and allows the fish to swim continuously, is probably more suitable for sturgeons (Kynard et al. 2011) thus, a side baffle ladder with continuous flow, no full cross-channel walls and abundant eddies for resting has proven to be a good solution for sturgeons and other moderate-swimming fishes (Kynard et al. 2011). Water velocity in the upstream part of a fishway should be lower in order to lessen fish fatigue, which can cause a decline in swimming capabilities (Katopodis et al. 2019).

3.3 Knowledge gaps

Swimming performance data are crucial for fish passage design, and a comprehensive swimming performance database, presented by Katopodis and Gervais (2016), showed that data for most sturgeon species are lacking, with some data provided for lake (*Acipenser fulvescens*), shortnose (*A. brevirostrum*) and pallid sturgeon (*Scaphirhynchus albus*). In cases when data for particular

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fish species are absent it is possible to use robust multi-species fatigue curves to predict swimming performance for a similar species, including sturgeons (Katopodis and Gervais 2016).

Data on burst speed is not available for sturgeon species and estimate of burst speed from extrapolation of prolonged fatigue curves would be of unknown reliability (Katopodis et al. 2019).

There is a problem with obtaining a sufficient sample size of large sturgeon for testing due to their low abundance in wild populations (Katopodis 2019).

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4 FISH PASSAGE FACILITIES FOR STURGEONS IN RUSSIA

During the 20th century, all large watercourses of the Azov, Black and Caspian Sea basins, important for the natural reproduction of anadromous sturgeons, were blocked by dams. Twenty-seven fish passes were constructed in Russia, of which 18 facilitate the passage of sturgeons (Pavlov and Skorobogatov 2014). These fish passes were constructed on the Don and Kuban rivers (Azov Sea Basin) as well as on the Volga and Terek rivers (Caspian Sea Basin) (Figure 2).

The fish passage facilities comprise a wide range of technical solutions to facilitate the migration of the target species. Hydraulic and mechanical fish lifts, fish locks, nature-like bypass channels and mobile devices for fish collection and transport are utilized with varying successes (**Fehler! Verweisquelle konnte nicht gefunden werden.**). Today, 50% of these facilities are no longer functioning (6 fish locks, one hydraulic and one mechanical lift, as well as one mobile device for fish collection and transport).

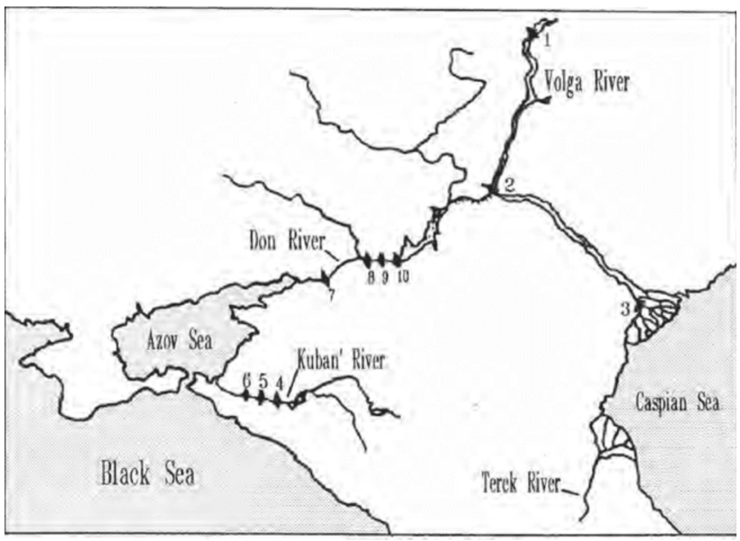

Figure 2: Dams on the Volga, Don, Kuban and Terek Rivers 1 – Saratovskiy dam 2 – Volgogradskiy dam 3 - Flow-divider; 4 – Krasnodarskiy dam; 5 – Fedorovskiy dam; 6 – Tikhovskiy dam; 7 – Kochetovskiy dam; 8 – Konstantinovskiy dam; 9 – Nikolaevskiy dam; 10 – Tsimlyanskiy dam (From Pavlov 1989)

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Table 4: The list of fish passages used by sturgeon in Russia

	Dam/River rkm/year/dam head	Fish pass / year / Dimension / passage efficiency/Attraction flow	Functioning, modification	Target species
1	Kochetovskiy / Don rkm 179 / 1920 / 1-3 m	Fish lock / 1972 Collection gallery 68x10 m / 17.7-66.6% / 0.6-2.0 m/s	In function (decrease in efficiency of fish lock)	sturgeons[1], shads, vimba bream
2	Konstatinovskiy / Don rkm 210 / 1982 / 5.5 m	Two fish locks / 1984 Collection gallery L=98 m Nature-like bypass / 1984 L=6 km W=22 m / / 1.1 – 1.6 m/s	Not in function (construction failure in area of fish attraction) In function	sturgeons[1], shads, vimba bream
3	Nikolayevskiy / Don rkm 251 / 1975 / 5.4 m	Two fish locks / 1979 Collection gallery L=134 m W=8 m Nature-like bypass / 1979 L=6.1 km W=20 m / / 0.92-1.45 m/s	Not in function (construction and building failure) In function	sturgeons[1], shads, vimba bream
4	Tsimlianskiy / Don rkm 309 / 1953 / 20 m	Hydraulic lift / 1955 Collection gallery 110x6 m / 0.8-1.0 m/s	In function (reconstructed in 1965-1972 to provide better fish attraction)	sturgeons[1], shads vimba bream
5	Flow divider Tikhovskiy / Kuban rkm 117 / 2005 /	Two fish locks / 2005	Not in function (there was no necessity to share water between the rivers)	sturgeons[1], vimba bream, pikeperch, bream
6	Fedorovskiy / Kuban rkm 153 / 1961 / 1-4 m	Fish lock / 1983 Collection gallery 76.2x9 m 0.8-1.8 m/s	In function (experiments were performed by changing the attraction flow)	sturgeons[1], vimba bream, pikeperch, bream
7	Krasnodarskiy / Kuban rkm 242 / 1974 / 13-17 m	Mechanical lift / 1974 Collection gallery 71x10 m 0.6-1.4 m/s	In function (lift repaired in 2013-2014; the optimization of the conditions in fish passage entrance)	sturgeons[1], vimba bream, pikeperch, bream
8	Flow divider / Volga River / delta	Two fish locks / 1975	Not in function	sturgeons[1], bream, carp, pikeperch
9	Volgogradskiy / Volga rkm 603 / 1960 / 23 m	Hydraulic lift / 1961 Collection gallery 85.2x8.5 m /10-15% 0.8-1.2 m/s	Not in function	sturgeons[1], vimba bream, pikeperch, bream

10	Saratovskiy / Volga rkm 1129 / 1967 /13-17m	Mechanical lift / 1969 Collection gallery 172x8 m 0.8-1.4 m/s	Not in function	sturgeons[1], vimba bream, pikeperch, bream
11	Kargalinskiy / Terek rkm 110 /	Fish ladder / 1956	Not in function	stellate sturgeon, salmon, vimba bream, carp

[1]sturgeons - beluga sturgeon, Russian sturgeon, stellate sturgeon, sterlet; L-length; W-width

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4.1 Fish passage facilities for sturgeons on the Don River

The Sea of Azov was the most productive sea in the world, but the construction of dams on the Don and Kuban rivers associated to the completion of reservoirs at the end of 1970s reduced its productivity and resulted in a massive decrease in the natural recruitment and resultingly the sizes of sturgeon populations as indicated by the catch data until the end of the 1980s (Lagutov 2009).

The River Don, with a length of 1,967 km, is one of the longest rivers in Europe. Before the building of the dam on the Don, the most important spawning region for sturgeon was situated in the 600-km-long sector between rkm 200 and rkm 800, with stellate sturgeon spawning habitats that were spread mainly in the downstream part, and that of beluga and Russian sturgeon in the upstream part of the sector (Boldyrev 2017).

Regulation of the Don for navigation which started in the period between 1914 and 1920, and continues today, as well as regulation for illegal fishing in the Don River and Azov Sea in the 1990s had a negative impact on sturgeon populations and induced a decrease in all three anadromous sturgeon species. The construction of dams on the Don River blocked the spawning migration of beluga, Russian and stellate sturgeons, making it impossible for them to reach historical spawning habitats. There are four dams on the Don River which are equipped with fish passage facilities.

4.1.1 Bagaevskiy dam

4.1.1.1 Location and Dimensions

The main problem for navigation on the River Don is still the low water level in the lower part of the river. This was the reason why construction of a new dam, the Bagaevskiy dam, was initiated in April 2018, downstream of the Kochetovskiy dam, to enable safe navigation on the river (Fig 3).

4.1.1.2 Passage Facilities

A fish lock and a nature-like channel are planned for the dam (Figure 4). Anyhow, there are strong reservations that this dam will have an additional negative impact on fish populations in the Don River.

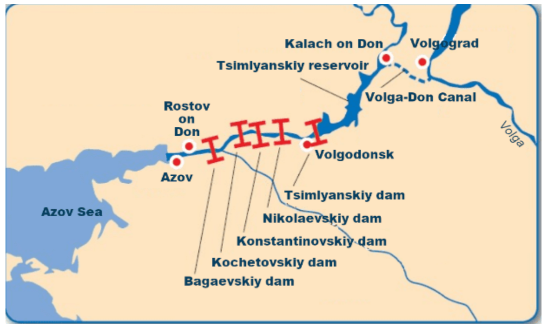

Figure 3: Bagaevskiy rkm 95, Kochetovskiy rkm 179, Konstantinovskiy rkm 212, Nikolaevskiy rkm251 and Tsimlyanskiy dam rkm 309 on the Don River (From article in journal "Mir Novostey" 30/10/2018)

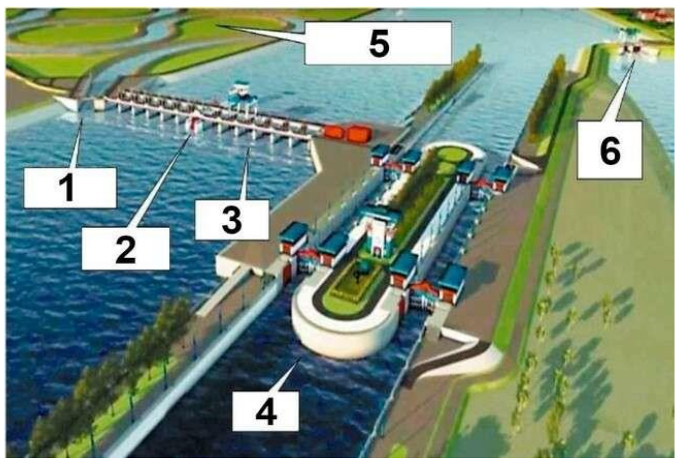

Figure 4: Scheme of Bagaevskiy dam with the position of the fish lock and the nature-like bypass channel 1) entrance into nature-like channel 2) fish lock 3) overflow dam 4) navigation lock 5) meandering channel for fish passage and spawning 6) earth dam (Created by Pavel Berkovskiy)

4.1.2 Kochetovskiy dam

4.1.2.1 Location and Dimensions

The Kochetovskiy dam was constructed for navigation purposes on the Don River at rkm 179 in 1920. The dam is 385 m long and 14.8 m high.

4.1.2.2 Passage Facilities

Although there was a plan for the construction of a fish pass facility on the Kochetovskiy dam, the dam was finished in 1920 without a fish pass (Troickiy 1930). The Kochetovskiy dam partly disables fish migration as the sluice gates are mainly in function during the summer-autumn

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period. This has been a more significant impact on beluga sturgeon migration than on Russian and stellate sturgeon because of the different periods of their migration in the Don River (Troickiy 1930). The Kochetovskiy Dam was out of function from 1942-1944 (World War II) and from 1954 until 1971 (Boldyrev 2017). The fish lock on the Kochetovskiy dam was built in 1972, 52 years after the dam was constructed and is still in function (Figure 5). This fish lock includes a 68-m-long and 10-m-wide collection gallery (with an attraction flow from 0.6-2.0 m/s), a 28-m-long operation chamber, two gates at the end of operation chamber for the control of flow regime, transfer and release of fish, an upper outlet chute and a control panel (Pavlov 1989).

4.1.2.3 Monitoring

The registration of fish species, their quantity and, if necessary, the collection of fish samples can be carried out at a fish retention grid. At onset of operation, the efficiency of sturgeon passage ranged from 17.7%-66.6%. The largest numbers of sturgeons that passed through this lock were in 1974, 1975, 1982 and 1983, with 1957, 2050, 1887 and 1990 individuals, respectively (Pavlov and Skorobogatov 2014). This fish lock was the first to be used for determination of optimal parameters for attraction, collection, sluice and release of fish. Many years of exploitation of the spillway had an impact on the riverbed, which produced changes in water velocity and consequently changed the site at which the fish were collected, impacting the efficiency of the fish lock (Pavlov and Skorobogatov 2014). A decrease in sturgeon passage at the Kochetovskiy dam was registered from 1990-1995, and during 2007, 2008 and 2009, 19, 10 and 9 sturgeon specimens, respectively, passed through this lock. Since investigations revealed the low efficiency of the fish lock (Anikhin et al. 2018), suggestions were made for the construction of a new fish pass comprised of a 9-km-long fish channel, with plans to finish the project by 2022.

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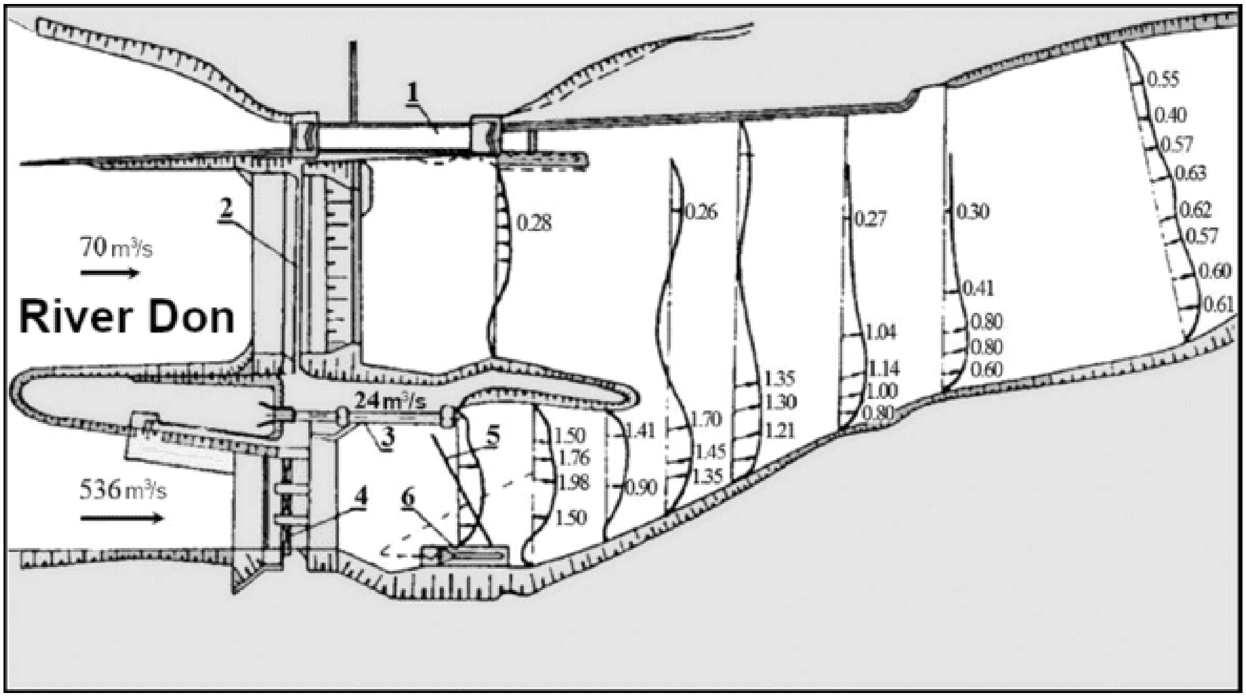

Figure 5: Schematic plan of Kochetovskiy dam with discharge (m³/s) in the headwater (left) and current velocity distribution (m/s) in the tailrace (right). Legend: 1 – navigation lock; 2 – dam; 3 – fish lock; 4 – spillway; 5 – electric fish barrier; 6 – experimental container for fish (From Pavlov and Skorobogatov 2014)

Mobile devices for fish collection and transport have been shown to be inefficient for sturgeons due to the existence of whirlpool areas at the ramp of the container, which disorients bottom-dwelling fish at a water depth greater than 4 m (Pavlov and Skorobogatov 2014).

4.1.3 Konstantinovskiy dam

4.1.3.1 Location and Dimensions

The Konstantinovskiy dam was constructed at 210 rkm in 1982. It is 21 km upstream of the Kochetovsky dam and 41 km downstream of the Nikolaevskiy dam. The length of the dam is 727 m and the height is 16 m.

4.1.3.2 Passage Facilities

There are two fish locks and one nature-like bypass channel on the Konstantinovskiy dam (Figure 6). The construction and technology at work at the two fish locks are similar to that on the Kochetovskiy dam. The lengths of the collection gallery, the operation and upper chamber are 98, 30 and 16 m, respectively.

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A nature-like bypass channel is 6 km long (Figure 6, No 1) with a 22-m width on the bottom, and an average depth of 2 m. Based on the estimated average water velocity of 1.2 m/s and a maximum of 1.4 m/s, the measured values showed a maximum velocity of 1.61 m/s and an average velocity of 1.1 m/s. The canal bed is covered in gravel and cobble stones (20-100 mm).

4.1.3.3 Monitoring

The fish locks were in operation from 1985-1987, and 16 fish species were recoded passing. Among the recorded fish were beluga, Russian and stellate sturgeon as well as sterlet; in 1985, 1986 and 1987 through these constructions 12, 120 and 77 sturgeon specimens passed, respectively (Pavlov and Skorobogatov 2014). The fish locks stopped working in 1988 as the fish did not concentrate in the area near entrance to the lock, and the lock was conserved in 1996. The main problems linked with the low efficiency of this fish lock were construction failure in the area of fish attraction, impossibility to create a proper attraction flow in the tailrace, as well as other construction deficits.

A nature-like bypass is still in function. During 1977 and 1984, the migration of 250 and 2590 sturgeon specimens was recorded in the bypass channel, respectively. In 1999 the eggs of stellate sturgeons were collected in the channel (Pavlov and Skorobogatov 2014).

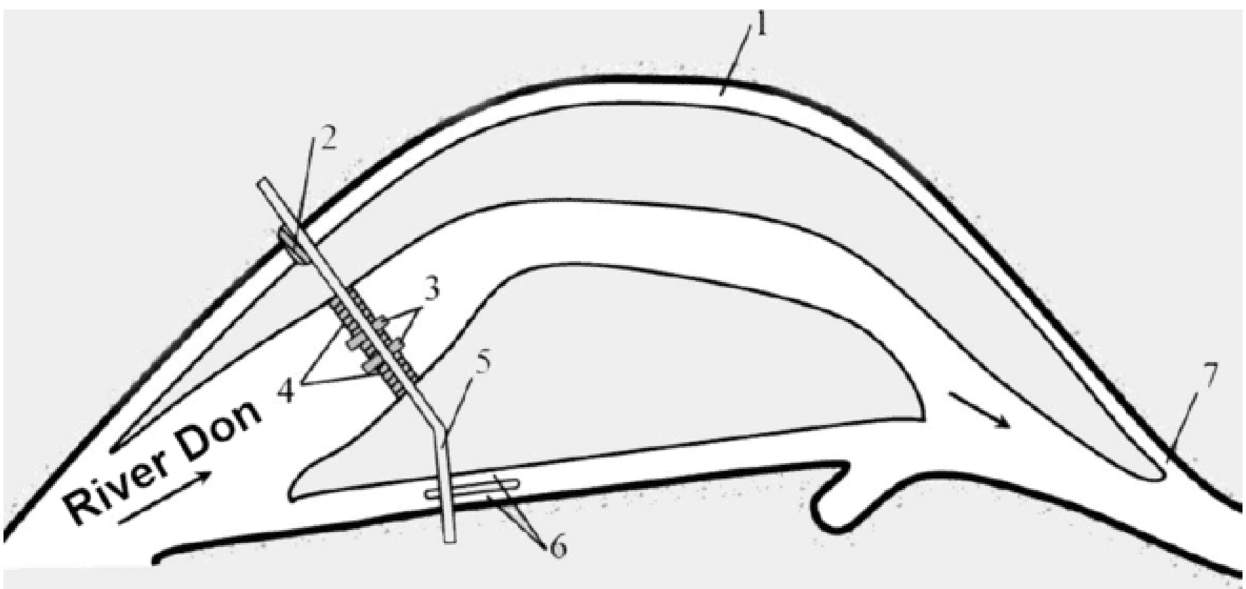

Figure 6: Konstantinovskiy dam on the River Don 1 – fish channel; 2 – construction for the regulation of water discharge; 3 – fish locks; 4 – spillway; 5 – road; 6 – ship locks; 7 – entrance to the fish channel (From Pavlov and Skorobogatov 2014)

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4.1.4 Nikolaevskiy dam

4.1.4.1 Location and Dimension

The Nikolaevskiy dam, the construction of which was planned during work on the Volga-Don Canal with the aim of achieving a depth for navigation to the Azov Sea, was finished at rkm 251 in 1974. The dam is 532 m long and 12.6 m high.

4.1.4.2 Passage Facilities

The dam has two fish locks (Figure 7) with a length of 134 m (collection gallery, operation and upper chambers have lengths of 81.5, 31 and 11.5 m, respectively) and a width of 8 m. The bottom of the collection gallery is 3 m above the tailrace bottom.

Additionally, one 6.1-km-long nature-like bypass channel is still in function. This channel has a 4.9-km- long artificial section and one 1.2-km-long old natural section (Figure 7, No 1). The width of the channel on the bottom is 20 m, and the bottom is covered with gravel and cobble stones (20-100 mm). Water velocity is regulated, and in specific conditions, with an average depth of 1.30-1.35 m, the average water velocity changes from 0.92 to 1.45 m/s.

4.1.4.3 Monitoring

Fish locks started operating in 1982 and in 1986 the passages of 2 beluga sturgeon, 141 Russian sturgeon, 62 stellate sturgeon and 176 sterlet through these two fish locks were recorded (Pavlov and Skorobogatov 2014).

Investigations showed that one of the locks was more efficient due to better creation of attraction flow. Also, one problem was that the bottom construction was responsible for the absence of optimal hydraulic conditions in the vicinity of the fish lock entrance. Due to construction and building failures, these fish locks were exploited at a low level and are now out of function.

Different fish species and their spawning have been recorded in the nature-like bypass channel (Pavlov and Skorovogatov 2014).

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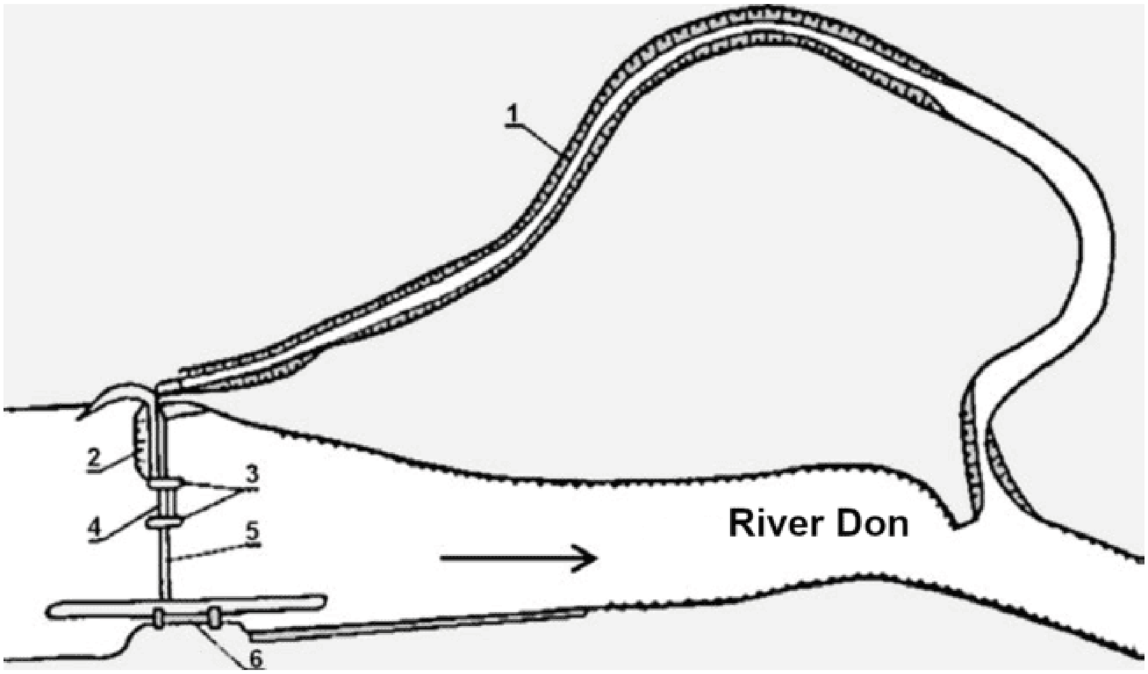

Figure 7: Nikolaevskiy dam on the Don River. 1 – fish channel; 2 – earth dam; 3 – fish locks; 4 – spillway; 5 – concrete overflow dam; 6 – ship lock (From Pavlov and Skorobogatov 2014)

4.1.5 Tsimlyanskiy dam

4.1.5.1 Location and Dimensions

The Tsimlyanskiy dam was built on rkm 309 in 1953 for the production of hydroelectric power and the reservoir is also a source of water for irrigation. It is also in use for flood control and the Tsimlyanskiy reservoir represents a part of the Don navigation route which is used for shipping materials between the upper and lower Don. The length of the dam is 495.5 m and its height is 43.7m.

4.1.5.2 Passage Facilities

Tsimlyanskiy dam has one hydraulic lift (Figure 8) which commenced work in 1955; it was reconstructed in 1965-1972 to provide better fish attraction. The collection gallery is 110 m long and 6 m wide, with a water depth from 6.5-13.6 m (Pavlov 1989). The fish pool is 18 m long and 5 m wide, with a water depth ranging from 4.2-11.6 m, and it is connected to the chute (area 7 x 5 m, height 36.8 m). The upper outlet chute is 65 m long and 6 m wide with a water depth that varies from 2 to 7 m. The hydroelectric turbine set and control panel can produce an attraction flow in the range from 0.4-1.0 m/s. This fish lift is still in function and operates from the start of April till the end of November.

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4.1.5.3 Monitoring

It is constructed for sturgeon, shads and vimba bream; however, sturgeons were recorded mainly during the first 8 years of operation until 1964 when sterlet passage reached 2,200 specimens per year (Pavlov and Skorobogatov 2014). At present, 23 fish species have been recorded using the fish lift, including sterlet.

Figure 8: Tsimlyanskiy dam on the Don River. 1 –overflow dam; 2 – fish lift (trapping pool); 3 – powerplant (From Pavlov and Skorobogatov 2014)

The study of Boldyrev (2017) of sturgeon populations downstream and upstream of the Tsimlyanskiy dam showed that during the 1950s and 1980s high concentrations of sturgeons were recorded downstream of dam. The first was the result of a concentration of natural sturgeon populations, while the second was the results of restocking activities. During the 1950s, mainly beluga and Russian sturgeon were present, while in the 1980s mainly Russian sturgeon was recorded. Trap-and-transport of sturgeon was organized during the period 1952-1962. The last Russian and stellate sturgeon individuals were recorded in the 1980s and 1990s, while single specimens of beluga sturgeon still exist in the reservoir. It is estimated that a small landlocked population of Azov beluga sturgeon existed in the Tsimlyanskiy reservoir. Monitoring of juvenile sturgeons during the 1950s and 1960s demonstrated their low number, after which beluga and stellate sturgeon juveniles were not recorded, and Russian sturgeon juveniles were observed only during high and average water levels.

4.1.6 Efficiency of fish passage use by sturgeons on the Don River

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Different fish passage facilities such as bypass channels, elevators and fish locks have been in operation on Don River. In general, the effectiveness of these installations was very variable with no clear result for a generally more effective design to be concluded. Some of the fish passes on the Don River provided sturgeon passage with an efficiency of 17.7-66.6% (during different years), as recorded on the Kochetovskiy dam at the onset of its operation. Since the abundance of sturgeon has decreased for different reasons among which the low effectiveness of the fish passage facilities and the loss of natural spawning grounds are only two, nowadays only a few sturgeon individuals are recorded in the fish passes. Furthermore, the hydrological conditions in the tailrace and forebay of the dams have changed significantly at some hydroelectric power stations and thus rendering the attraction flows for the fish passage facilities ineffective. Hydrological and hydrodynamic investigations would be required in order to allow the readjustment and reconstruction of the facilities to achieve a more efficient fish passage.

4.2 Fish passage facilities for sturgeons on the Kuban River

The length of the Kuban River is 870 km. There are three dams on the Kuban River: the Tikhovskiy water divider at 117 rkm with two fish locks, the Fedorovskiy dam at 153 rkm with one fish lock, and the Krasnodarskiy dam at 242 rkm with one mechanical lift. Before the construction of the dams the spawning locations for sturgeons were located upstream of Krasnodarskiy dam: for stellate sturgeons they ranged from rkm 270-470, for ship sturgeon up to the mouth of the Laba River, for beluga up to Ladozhskaya, and for Russian sturgeon to Tbilisskaya (Zamotajlov 2007).

4.2.1 Tikhovskiy dam

4.2.1.1 Location and Dimensions

The Tikhovskiy dam located 117 km from the river mouth (Figure 9) was built in 2005, serving as a flow divider. The length of the dam is 350 m and the height is 9.6 m. It is situated 0.6 km upstream from the place where the river divides into two main delta branches (Kuban and Protoka). The water divider currently is not operational.

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Figure 9: Tikhovskiy dam with fish locks. 1 – ship locks; 2 – fish locks (From Pavlov and Skorobogatov 2014)

4.2.1.2 Passage Facilities

Two fish locks on this dam were constructed similarly to the type established on the Fedorovskiy dam (Pavlov and Skorobogatov 2014).

4.2.1.3 Monitoring

The fish passage facilities are not in function since the dam is not operational. No monitoring is carried out.

4.2.2 Fedorovskiy dam

4.2.2.1 Location and Dimensions

The Fedorovskiy dam was built in 1961 at rkm 153 with one ship lock. The dam is 300 m long and 9 m high.

4.2.2.2 Passage Facilities

One fish lock and one technical passage were built for fish to pass. A technical passage (Soldatov) was built in 1967 (Figure 10). This technical fish passage had length 275 m, width 10 m and seven steps (length 12 m; difference between levels 0.8 m). During 15 years of work (1967-1982) there was no records of sturgeon passage. The attraction flow which was close to the threshold (~0.2 m/s) was the main reason for the failure of this fish passage on the Fedorovskiy dam (Palov and Skorobogatov 2014). Sturgeon passage through the Fedorovskiy Dam was possible only 21 years

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after the dam was constructed, i.e., when the fish lock was finished. Construction of the fish lock was finished in 1982. The fish lock has a crowding chamber that is 76.2 m long and 9 m wide, a 24.5m-long working chamber, and a 3.50m upstream chamber (Pavlov and Skorobogatov 2014).

4.2.2.3 Monitoring

Experiments were performed by changing the attraction flow, which showed that optimization of conditions can increase the efficiency of fish attraction by 50-60%. Fish passage of 29 species, including sturgeon, was recorded. The best results for passage of sturgeons were obtained during the first years of exploitation and the maximum number of sturgeon specimen passages through this lock was obtained in 1987 when 2,031 stellate and 100 Russian sturgeon specimens were recorded (Pavlov and Skorobogatov 2014).

Figure 10: Fedorovskiy dam on the Kuban River. 1 – ship lock; 2 – fish lock; 3 – spillway; 4 – technical passage Soldatov (From Pavlov and Skorobogatov 2014)

4.2.3 Krasnodarskiy dam

4.2.3.1 Location and Dimensions

Krasnodarskiy dam is located at 242 rkm on the Kuban River and construction of this dam was finished in 1974. The dam is 11600 m long and 22 m high.

4.2.3.2 Passage Facilities

The Krasnodarskiy dam has one mechanical fish lift located in the centre of the dam adjacent to the turbine outlet. It started with operation in 1974. The length of the collection gallery is 71 m and the width is 10 m; water depth ranges from 2.5 to 9.8 m (Pavlov and Skorobogatov 2014).

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There is an electric barrier for fish near the entrance to the fish passage (Figure 11). After 30 years of exploitation, the fish lift was repaired in 2013-2014. Hydraulic investigations showed that it is possible to produce the necessary attraction flow (0.6-1.4 m/s) at the entrance to the fish passage, but there are considerable differences in the water velocities in the downstream chamber, as well as turbulence, and it is thought that the downstream chamber should be 30-40 m longer (Pavlov and Skorobogatov 2014). Investigations also showed that after 30 years of exploitation of the Krasnodarskiy dam, the observed hydraulic conditions in the tailrace were the result of changes in the bottom topography.

4.2.3.3 Monitoring

Experiments examining the effects of the optimization of the conditions in the fish passage entrance and mode of operation for fish attraction performed during 2001-2003 showed that the efficiency of fish passage could increase on average 1.3-1.4-fold. Twenty-nine fish species passed through the dam by fish lift, and the highest number of sturgeons was recorded in the period 1986-1989 when 100 sturgeon specimens were recorded (beluga sturgeon, Russian sturgeon, stellate sturgeon).

Figure 11: The Krasnodarskiy dam on the Kuban River. 1 – spillway; 2 – mechanical fish lift; 3 – electric barrier for fish (From Pavlov and Skorobogatov 2014)

Investigation of the fish passage at the Krasnodarskiy dam by fish lift was performed during 2017 when 20 fish species and 454,343 mainly cyprinid fish specimens were recorded (Polin and Strechenko 2018). The highest number of fish in the fish lift was observed in May and October (the lift did not operate in June due to technical reasons, and in January and February, in accordance with the rules for lift exploitation). Only 5 sterlet specimens were recorded. The last passage of Russian sturgeon was recorded in 2011, of beluga sturgeon in 2013 and of stellate

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sturgeon in 2016 (Polin and Strelchenko 2018). The numbers of sturgeon migrants that passed the Fedorovskiy and Krasnodarskiy dams in the period 1983-1987 are presented in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Table 5: The number of migrants transported by the fish lock and fish lift at the Kuban River and estimation of fish pass efficiency (Lagutov and Lagutov 2007)

Year	Number of sturgeon migrants Transported at Fedorovsk dam	Number of sturgeon migrants Transported at Krasnodar dam	Efficiency (%)
1983	798	24	3.0
1984	1,015	61	6.1
1985	605	20	3.5
1986	1,092	43	4.0
1987	2,139	47	2.3

4.2.4 Efficiency of fish passage use by sturgeons on the Kuban River

The efficiency of sturgeon passage at the Fedorovskiy dam is not possible to determine as data on the numbers of sturgeon that approached the dam are unavailable. The number of sturgeon specimens that passed via the lift on the Krasnodarskiy dam during the 1980s represents 2.3-6.1% of the number of sturgeon specimens that passed via the fish lock on the Fedorovskiy dam. Sturgeon spawning in the Kuban River upstream dam complex had not been observed from the 1980s due to lack of spawners, while official reports contained data about efficient fish passage and transfer of hundreds of sturgeon migrants to the spawning grounds (Lagutov 2009). The experiments on the fish lock and fish lift showed that by changing the attraction flow it is possible to improve conditions and to increase the efficiency of fish attraction by 50-60% (Fedorovskiy fish lock) or to increase fish passage efficiency 1.3-1.4-fold on average (Krasnodarskiy fish lift).

4.3 Fish passage facilitation on the Volga River

The Volga River, with a length of 3530 km, is the longest river in Europe. There are 12 hydropower dams in the Volga River Basin and 8 large reservoirs on the Volga River (Figure 12); however, fish passes were constructed on only three dams: two fish locks on the flow divider of the Volga River delta, one hydraulic lift on the Volgogradskiy dam, and one mechanical lift on the Saratovskiy dam (Ruban et al. 2018). At present, none of the fish passes are operational.

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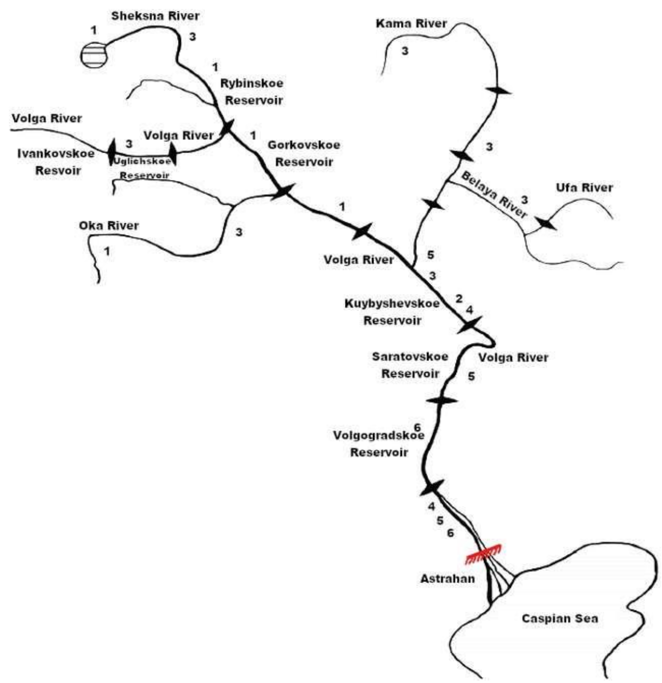

Figure 12: Dams (black marks) and flow divider (red marks) on the Volga River Basin and historical sturgeon spawning habitats for winter and vernal race: 1, 2 – winter and vernal race of beluga; 3,4 – winter and vernal race of Russian sturgeon; 5,6 – winter and vernal race of stellate sturgeon

The spawning habitats on the Volga River for Russian sturgeon occupied 1,000 ha, while after construction of the Volgogradskiy dam, the surface of the spawning habitats decreased by 80% (Lure 2011). In accordance with the Atlas of spawning habitats of sturgeons in the Volga River Basin, the total spawning habitats of sturgeon decreased from 3,300 ha to 430 ha as the consequence of Volgogradskiy dam construction. Fisheries at the Volga-Caspian Basin were the main factor impacting sturgeon populations before dam building. Dam construction in the upstream part of the Volga River had no big impact on natural sturgeon spawning but the construction of dams in the lower part of the Volga River had a detrimental effect on their natural reproduction. It is possible to discriminate three periods in dam building on the Volga River: 1) 1937-1958 when Ivankovskoe, Uglichskoe, Rybinskoe and Gorkovskoe reservoirs were formed which impacted shortening of migration route and loss of the most upstream habits of sturgeons, while a high percentage of spawning habitats was still available; 2) 1958 – middle of 1980 after the Volgogradskiy and Saratovskiy dams were built, which resulted in the destruction of all spawning habitats for beluga, 80% of the spawning habitats of spring race of Russian sturgeon and 60% of spawning habitats of stellate sturgeon (Figure 12). Natural spawning of sturgeons preserved only in the sector of the Volga River between Volgogradskiy dam to the Volga Delta; 3) from the middle of 1980 to the present when poaching and water pollution annulated all achievements by restocking and other measures for sturgeon preservation (Ruban et al. 2018).

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4.3.1 Flow divider in the Volga River delta

4.3.1.1 Location and Dimension

The flow divider in the Volga River delta was built in the upper part of the delta in 1977 to provide better spawning in the eastern part of the delta (with known spawning habitats), by increasing the water level during years with a low water level. The dam length is 1,100 m with additional the earth dam of about the same length in the eastern part. It was exploited only 6 times (1977, 1978, 1982, 1983, 1988, 1989) and the dam was closed for 160 days in total (20-30 days at the end of flooding) (Ruban et al. 2018).

4.3.1.2 Passage facilities

There are two fish locks on this dam. The fish locks are similar to those on the Don and Kuban rivers except for some changes, such as a shorter downstream chamber, which is only 50 m long. The width of each fish lock is 10 m. A chamber with such small dimensions cannot receive more than 70 sturgeon per cycle. The flow divider and fish locks are not in function (Pavlov and Skorobogatov 2014), allowing free migration.

4.3.1.3 Monitoring

During the exploitation of the flow divider, it was shown that a wrong decision for the position of fish locks on the dam was made. Monitoring of sturgeon migration showed that they concentrate in the vicinity of the earth dam and that sturgeon delay in the tailrace could have a negative impact on fish gonads, with the most pronounced effect on stellate sturgeon (Ruban et al. 2018).

4.3.2 Volgogradskiy dam

4.3.2.1 Location and Dimension

The Volgogradskiy dam was constructed at rkm 603 in 1958. It consists of a 725 m long and 44 m high concrete dam and 3,250 m long earth dam which result in a reservoir with a surface area of 3,117 km^2.

4.3.2.2 Passage facilities

One hydraulic fish lift was constructed and commenced operation in 1961. Before the fish lift started to work, adult Russian sturgeon was caught downstream of Volgogradskiy dam, transported and released to the reservoir 100-130 km upstream of the dam: 10,000 and 20,000 of specimens were transported in 1959 and 1960, respectively (Ruban et al. 2018). The fish lift has a two-stream collection gallery which is 8.5 m wide, 85.25 m long, with water depth ranging

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from 5.7 to 14.4 m, two vertical shafts (8.5 x 8.5 x 36.9 m), an upper 100 m long, a 12-m-wide one-stream chute with three openings, a turbine set for the creation of an attraction flow in the collection gallery and a control panel (Figure 13). Control of the fish lift was performed automatically with 1.5-2.0 hour cycles (Pavlov 1989). The fish lift worked during every year from May until October (1500 lifts) until 1988. It was conserved in 1999.

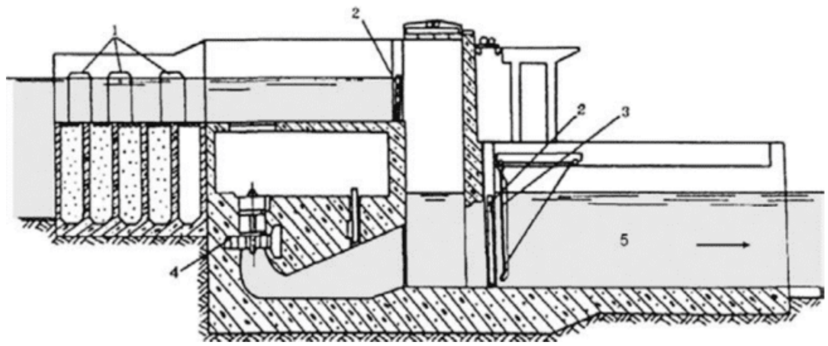

Figure 13: Hydraulic fish lift on the Volgogradskiy dam. 1 – openings for fish release; 2 – operational gates; 3 – crowding device; 4 – hydroelectric unit; 5 – collection gallery (From Pavlov and Skorobogatov 2014)

4.3.2.3 Monitoring

The highest numbers of sturgeon specimens were transported by this lift at the start of its work when 200-700 thousand sturgeon migrated from the Caspian Sea to the Volgograd dam. At that time, an average of 20,000 sturgeon specimens per year passed via the fish lift, and in 1967 a maximum of 60,000 sturgeon specimens was recorded (Pavlov 1989). Each year, 2000 to 52,000 Russian sturgeon and 20 to 1,300 stellate sturgeon passed. Sturgeons that were transported by lift represented 10-15% of all sturgeon specimens that approached the dam. Aside from sturgeon, many other fish species passed through the fish lift (more than 1 million individuals).

Nowadays almost no sturgeon approach the dam. After 1988, when the fish lift was not in function, single specimen of Russian and stellate sturgeon were recorded to pass the dam by ship lock, but the passing of beluga sturgeon was not recorded (Shashulovskiy and Ermolin 2005).

4.3.3 Saratovskiy dam

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4.3.3.1 Location and Dimension

The Saratovskiy hydropower dam was built during the period 1956-1967 at rkm 1,129. It is 1,260 m long and 40 m high dam which forms a reservoir with surface area of 1,831 km^2.

4.3.3.2 Passage facilities

On this dam one mechanical lift was constructed that commenced operation in 1969. It has a downstream chamber which is 172 m long, 8 m wide, with water depth ranging from 7-12.5 m, a shaft (6 x 8 m), work chamber with a container and an upstream chamber with 8-m-wide pool, a turbine hydro-set and a control panel (Pavlov 1989). It is possible to adjust the flow in the downstream chamber from 0.4 to 1.4 m/s.

4.3.3.3 Monitoring

The numbers of sturgeon specimens that have passed via this lift represent 0.46-2.00% of the number of sturgeon specimens that passed through the Volgogradskiy dam during the 1960s and 1970s (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

Table 6: Data about Russian sturgeon passage through fish lifts on the Volgograd and Saratovskiy dam during 1969, 1973, 1975, 1976 and 1978 (Pavlov and Skorobogatov 2014)

Year	No of passed R. sturgeon on Volgograd dam (n1)	No of passed R. sturgeon on Saratov dam (n2)	n2 / n1 x 100
1969	51 900	352	0.68
1973	60 800	278	0.46
1975	27 800	235	0.84
1976	27 300	559	2.00
1978	35 700	249	0.69

During 1973 there were 395 lifts and only 281 sturgeon specimens were passed mainly Russian sturgeon (278) and only 3 beluga sturgeon (Ruban et al. 2018). When the Volgogradskiy fish lift was abandoned, the work of the Saratovskiy fish lift was also abandoned. The view is that both these lifts should be exploited.

4.3.4 Efficiency of fish passage use by sturgeon on the Volga River

The efficiency of sturgeon passage at the Volgogradskiy dam was 10-15% during the 1960s. The number of sturgeon specimens that passed at the Saratovskiy dam represented only 0.49-2.00% of the number of sturgeon specimens that passed at the Volgogradskiy dam during the period from 1969-1978. Neither the hydraulic nor the mechanical lift are in function anymore because of the decrease in sturgeon populations in the Volga River. The main reasons for the decrease

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are the overfishing of sturgeon in the Caspian Sea and the Volga River, illegal fishing, the decrease in natural sturgeon reproduction and pollution (Lure 2011).

4.4 Fish passage facilities for sturgeons on the Terek River

The Terek River is 623 km long. There are three fish passes on the Terek River and its tributary, the Cerek River. The Kargalinskiy dam was built in 1956 on the Terek River 110 km from the Caspian Sea for irrigation purposes. A fish ladder was constructed in 1956 for migration of stellate sturgeon, Caspian salmon (*Salmo ciscaucasicus*), vimba bream (*Vimba vimba*), carp (*Cyprinus carpio*) and other fish species (Pavlov and Skorobogatov 2014), but due to oversights in design, it was covered by sediment during the first years of operation and is no longer in use (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

4.5 Efficiency of fish passage use by sturgeon in Russia

A more or less efficient sturgeon passage was recorded on fish lifts and locks as well as on the bypass channel in Russia, especially during the first years following their construction when sturgeon abundance was high in rivers belonging to Azov and Caspian Sea basins. Construction failures in the area of fish attraction, too low capacities, lack of providing downstream migration options, as well as hydraulic conditions in the vicinity of the fish pass entrance were the main reasons for the low efficiency of the fish passes.

No systematic analysis is available to verify the principal benefits of the different designs. In addition, related errors in the design, maintenance and operation have led to a substantial loss of effectiveness. It is obvious though that even under conditions of abundant populations the fish passage facilities have been too small and suboptimally designed and operated to facilitate the transfer of the fish in the vicinity of the dam. If in a series of dams, a transfer efficiency of 80- 90 % is mandatory to ensure fish reaching the headwaters at all the designs presented here failed massively.

Secondly, the unclear fate of fish that crossed the dams upstream upon their return adds to the concerns about the qualities of the solutions offered since the impact of a total loss of a given generation of spawners during downstream migration would have been detrimental for the populations too.

But in case of the Kochetovskiy dam even 52 years passed between dam was built and the first fish passage facility was constructed, good results in the number of beluga, Russian and stellate sturgeon passing through the dam were recorded. A total of 2-34 beluga, 244-1034 Russian and 52-1006 stellate sturgeon passed annually through the Kochetovskiy fish lock during the period 1983-1987.

Improvement of fish lift operation on the Krasnodarskiy dam revealed the potential to achieve

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better efficiency by optimizing the conditions at the fish passage entrance and the mode of operation of fish attraction. The other fish lock and lifts also require improvement. Nowadays, the main problem is the low abundance of sturgeon in the Azov and Caspian Sea basins. Improvement of fish passage facilities could be performed alongside restocking activities and monitoring of sturgeon behaviour.

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5 FISH PASSAGE FACILITIES AND THEIR UTILIZATION BY STURGEON IN THE USA AND CANADA

All sturgeon in North America have disappeared from 22% of their historical range (Jager et al. 2016). Sturgeon are present in nearly every major river system in North America (Figure 14). In addition to overfishing, disruption of river continuity by dam building has impacted negatively on sturgeon populations by preventing upstream and downstream migrations and reducing the quality of fish habitats.

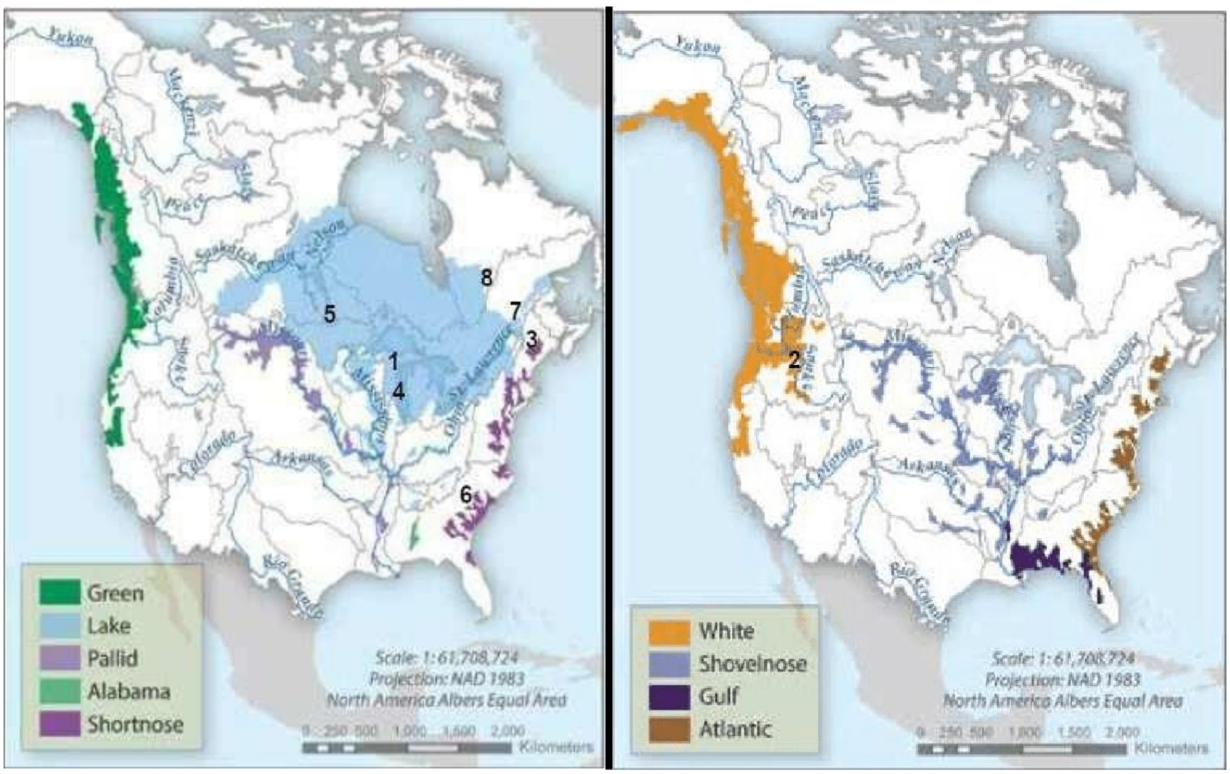

Figure 14: Distribution of sturgeon of special conservation concern in the United States and Canada. Sources: Scott and Crossman (1985). 2013 Data from NatureServe - Efficiency of fish passage on the: 1) Menominee River 2) Columbia River 3) Connecticut River 4) Fox River 5) Winnipeg River 6) Cooper River 7) Richelieu River and 8) Eastmain River are presented in this report.

Different types of fish passes have been built to improve the established conditions. Despite this, still no searchable database with specific information on fish passes exists. One of these national databases was initiated in Canada in the framework of the CanFishPass project in 2009, which showed that of the majority of fish passes constructed for salmonids in Canada, only 9% underwent scientific, biological evaluation (Hatry et al. 2013). In the USA there is a scarcity of information relating to fish passage by sturgeon and data about their efficiency. The list of

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sturgeon-specific passage in North America is presented on **Fehler! Verweisquelle konnte nicht gefunden werden.**, and is based on literature search and contact with relevant experts in the USA and Canada. These fishways include fish lifts, fish ladders, navigation locks, and trap-and-transport. Investigations were mainly done on lake, shortnose and white sturgeon.

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Table 7: The list of fish passages used by sturgeon in North America

	Dam / River rkm / year / dam head	Fish pass / year Dimension / efficiency Attraction flow	Functioning, modification	Target species	Sturgeon species
1	Menominee / Menominee Rkm 4 / 1925 / 8 m	Fish lift / 2015 Hooper 3 x 4.5 x 1 m / 7.1-7.9%	Changes in operation time and increase of fish lift efficiency by higher attraction flow	lake sturgeon	lake sturgeon
2	Park Mill / Menominee River Rkm 6.1 / 1920 / 6.7 m	Trap and transport / 2015		lake sturgeon	lake sturgeon
3	Bonneville / Columbia Rkm 235 / 1934 / 21.3 m	Fish lock / 1938 Two pool and weir fish ladders	Not in function since 1971[11]	anadromous salmonids	white sturgeon
4	Dalles / Columbia rkm 309 / 1957 / 24.4 m	Two overflow weir ladders with orifices / L=540 m W=9.14 m (East) W=7.32 m (North) 0.5-1.2 m/sec		anadromous salmonids	white sturgeon
5	John Day / Columbia rkm 345 / 1950 / 30.8 m	Two pool and weir fish ladder / 1968 W=7.3m	2009-2010, North ladder exit modification for lamprey	anadromous salmonids	white sturgeon
6	Holyoke / Connecticut rkm 140 / 1849 / 9 m	Two fish lifts / 1950s and 1976	After engineering works passage of sturgeon increased	American shad Atlantic salmon	shortnose sturgeon
7	Eureka / Fox rkm 15 / 1877 / 1 m	Plunge pool fishway / 1988 L=30 m	Creation of rapids (positive impact on fish attraction into the fishway)	lake sturgeon, walleye	lake sturgeon
8	Seven Sister GS / Winnipeg rkm 72 / 1931-1952 / 18.6 m	Trap and transport		lake sturgeon	lake sturgeon
9	Pinopolis / Cooper rkm 77 / 1941 / 42 m	Navigation lock, trap-and-transport		Alosa spp	shortnose sturgeon
10	St.Ours / Richelieu rkm 18 / 2.65 m	Vianney-Legendre vertical slot fishway / 2001 L=85 m / 36.4% 1 – 1.4 m/s		American eel, Cooper redhorse, lake sturgeon, American shad	lake sturgeon
11	Eastmain-1 / Eastmain River / 2006 /	Pool-weir type of fish pass / 2006 L=150 m W=15 m / up to 80%	Reducing of flow velocity in fish pass from 2 m/s to 1-1.4 m/s	lake sturgeon, walleye, lake whitefish, norther pike, suckers	lake sturgeon

[1] The fish locks constructed on the first dams on the Columbia River (Bonneville, The Dalles) were abandoned in favour of pool-type fish passes (Larinier and Marmulla 2003); L-length; W-width

5.1 Fish passage facilities and their utilization by lake sturgeon (*Acipenser fulvescens*)

5.1.1 Fish passage facilities for lake sturgeon on the Menominee River

The Menominee River is approximately 187 km long. It enters Green Bay on Lake Michigan and represents the water boundary between Michigan and Wisconsin. There are 10 dams that separate it into run-of-river- impoundments. The Menominee River supports the largest naturally-reproducing stock of lake sturgeon in Lake Michigan, but the juvenile habitat downstream of the lowest dam is of low suitability for the species (Schulze 2017).

5.1.1.1 Menominee and Park Mill dam

5.1.1.1.1 Location and Dimension

The two lowest dams near the river mouth are the Menominee hydroelectric dam situated 4 km upstream from Lake Michigan, which began commercial operation in 1925, and the Park Mill hydroelectric dam situated 1.5 km upstream of the Menominee dam (Figure 15).

5.1.1.1.2 Passage facilities

The Menominee River Fisheries Plan which was completed in 1992 recommended the construction of fish passages on 5 hydroelectric dams. This also included the construction of a fish pass on the Menominee and Park Mill hydroelectric dam with lake sturgeon as the priority fish species, but considering other fish species too (Ultrup et al. 2009). The fish lift on the Menominee dam was completed in 2015 inside an empty turbine bay. A 10-m high tower elevates a hopper (3 x 4.5 m, water depth up to 1 m) which is emptied into a tank (diameter 3.4 m) where it is possible to sort fish, take biological samples, and tag fish (Figure 16). Due to the existence of a second dam 1.5 km upstream of the Menominee dam (the Park Mill dam), passage also includes the transporting of captured sturgeon above the Park Mill dam via a tank trailer towed by a truck (Figure 15). Sub-samples of captured adult lake sturgeon were transported upstream of the Park Mill dam (Figure 15). The downstream bypass on the Menominee dam is about 1 m wide and 1-2 m deep open channel (3.4 m^3/s), and on Park Mill dam a 1.2 m diameter pipe that were constructed specifically to provide a continuous downstream passage route for fish through these dams (Phase I and Phase III, Figure 15). Both downstream structures were constructed (steep angle with high velocities; approx. 0.5 m drop between the downstream end of passage and river surface) to not allow for upstream passage (Porter 2019).

5.1.1.1.3 Monitoring

Beginning in May 2015, the fish lift has regularly operated during spring (March-May) and autumn (August-November) following a randomly stratified schedule that varied with the time of day, frequency lift, and amount of attraction flow in order to determine optimal operation procedures. The fish lift captured 22 fish species in 2016, whereas during the spring and autumn of 2017 and 2018 the elevator captured 34 fish species in 943 lifts. Lake sturgeon was represented with 4-8% of the total fish capture, and 84, 124 and 187 lake sturgeon were

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processed in 2016, 2017 and 2018, respectively, with peak catches during May 3-12 and October 2-7 (Donofrio 2017). Movements of lake sturgeon in the area of these two dams were monitored using acoustic telemetry, radio telemetry and ARIS sonar.

Results of investigations carried out from 2017 and 2018 were used to modify the procedures for lift operations in 2019. They operate during evening or night hours and longer soak periods, and at a higher attraction flow applied to achieve better efficiency. In the spring of 2019, 67 sturgeons were collected in 152 lifts from April 26 to May 18; 65 of the fish were captured between May 3-11 in 68 lifts. In the autumn, 163 sturgeons were collected in 42 lifts during just 10 evenings of operation from August 26 to September 9.

There is relatively good success in the passage of adult lake sturgeon upstream through the Menominee dam using a fish lift. It was shown that the lift was fairly efficient during spring 2-3 weeks before spawning and in late summer/early autumn (it was common during late August and early September to capture 20-30 adult lake sturgeon in the lift in 2-3 hours of lift operation during early night hours). The translocation of about 100 mature lake sturgeons per season was the goal in the early years of evaluation, which was possible to achieve depending on river flow conditions within 2-3 weeks (with 2 people operating the lift for a few hours each night). Additional time is required to process, sex and tag the fish. It was estimated that about 1,000 lake sturgeons are in the river during passage operation and with this level of lift efficiency it was possible to catch 10-20% of the population each year. It would be possible to capture a higher amount of fish if the lift were operated for more hours each day or more weeks per year.

The highest captures of lake sturgeons were recorded at water temperature around 12.7°C and during a decrease in river discharge. The attraction flow was shown to be very important. Based on acoustically- tagged lake sturgeon, the elevator capture efficiency was 7.1-7.9% during the spring of 2017 and 2018 (Raabe 2019), and was much higher in 2019 when operating during peak evening hours and with higher attraction flows.

There were no recorded injuries of lake sturgeon during upstream passage by fish lift on the Menominee dam. As the process of fish sorting is not automated, people manually sorted sturgeon from other fish species captured by the fish lift.

Continual telemetry studies show that about 85% of the fish that are passed upstream moved back down through the dams within a few months after the spring spawning season, and nearly 100% have moved back downstream within 1-2 years. Most downstream movement was through open spill gates in the Park Mill and Menominee dams. There is less information about injuries during downstream migration but several fish that have been recaptured again in the fish lift after they have moved back down river did not show any signs of damage. Occasionally when these spill gates were closed during low flow periods, lake sturgeon used the downstream bypasses. Video-recording data supports that there is little opportunity for injury for fish passing through these downstream passage flumes. There are narrow-spaced racks installed across the intake bays for the hydroelectric generators at both dams, and the water

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velocities through these racks are kept below 0.5 m^3/sec, and there have not been problems with adult fish getting impacted on these racks (Robert Elliott, personal communication).

Figure 15: Menominee and Park Mill Dam sturgeon passage facilities (truck transport upstream of the Park Mill dam). Phase I, downstream passage at Park Mill was constructed in 2013-2014 and completed in January 2015; Phase II, an upstream elevator and sorting facility at Menominee was constructed in 2014-2015 and placed in service in 2016; Phase III, the downstream passage at Menominee was constructed in 2016 and began operating in 2017; The upstream pointed arrows denote the upstream migration/movement of lake sturgeon. Photo credit: Eagle Creek Renewable Energy

5.1.1.2 Efficiency of fish passage use by sturgeon on the Menominee River

The Menominee fish lift represents a rare case where sturgeon was the priority fish species and continual work performed during few starting years was used to establish the best conditions for sturgeon passage. The efficiency of sturgeon passage by lift was 7.1-7.9 % during 2017-2018 but was much improved in 2019 by higher attraction flow and operation during peak evening hours. The other benefit of this fish lift is the collection of data about hundreds of non-targeted fish species that also help in management of the Menominee River fisheries. The fish lift was constructed on the Menominee Dam 90 years after dam construction and there was no upstream passage of lake sturgeon from 1925 until 2015. However, a population continued to persist at low levels in the upper Menominee River, and young sturgeon were stocked upriver for about 20 years before the fish lift was constructed. In spite of the long timespan in between quite a number of lake sturgeons monitored passing the obstacles after construction of fish lift.

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Figure 16: Upstream fish lift and sorting facility. Photo credits: Rob Elliott, U.S. Fish and Wildlife Service

5.1.2 Fish passage facilities for lake sturgeon on the Fox River

The Lake Winnebago System (east central Wisconsin) supports one of the largest lake sturgeon populations in North America. Two major watersheds flow into Lake Winnebago: the large Wolf River and the smaller upper Fox River watersheds. The first dam on the Fox River situated 200 km upstream of the lake still provides spawning and nursery areas for lake sturgeon. On the Fox River the first dam is only 15 km upstream from the lakes (Bruch 2008).

5.1.2.1 Eureka dam

5.1.2.1.1 Location and dimension

The Eureka dam on the Fox River was constructed in 1877, its main purpose was safe commercial navigation between Lake Michigan and the Mississippi River basin. But the development of railroads reduced the use of waterways and traffic on the Fox River, which stopped completely in 1938, and in 1951 the navigation system closed down. The Eureka navigation lock operated until 1953, but recreational boats used it during the 1960s-1980s. The dam was rebuilt in 1962. The first attempts to construct fishways on the Eureka dam in the 1940s and 1950s were unsuccessful, and with reconstruction of the sluice gates on the dam in 1962, fish passage was possible only during extreme flood events.

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5.1.2.1.2 Passage facilities

A new fish pass, a three-step plunge pool 30-m long to accommodate 1 m of head, was constructed in 1988 (Figure 17) This fish pass opened an additional 50 km for spawning and nursery habitats up to the next barrier (Bruch 2008).

5.1.2.1.3 Monitoring

Lake sturgeon and walleye (*Sander vitreus*) passage was recorded in the first year of fish pass operation in 1989, with continual passage of lake sturgeon and even its use for spawning by lake sturgeon every year from 1989 to 2006 due to the prevailing optimal conditions (water velocity, substrate). Downstream migration presented a problem because of injury to juveniles by the undertow below the dam. This problem was solved by creating the Eureka Rapids by dumping limestone rock below the dam in 1992-1993 (Figure 18). The rapids have also had a positive impact on fish attraction into the fish pass and are responsible for the creation of a new spawning area for sturgeons below the dam. Construction of the fish pass and the creation of rapids provide for undisturbed upstream and downstream migration of sturgeon at the Eureka dam, which has been proven by acoustic and radio telemetry studies on the Winnebago System (Bruch 2008).

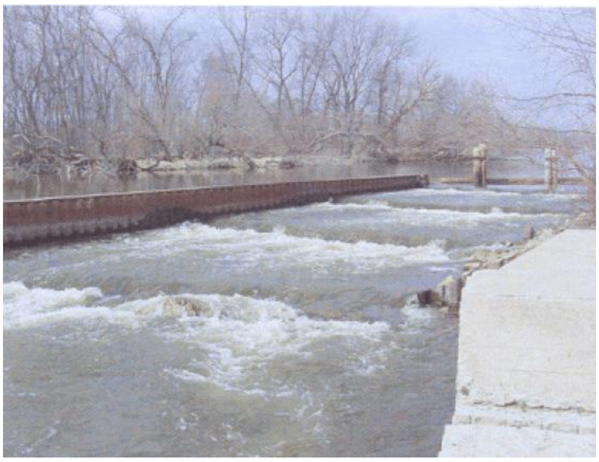

Figure 17: Three-step plunge pool fishway constructed on the Eureka dam in 1988 (From Bruch 2008)

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Figure 18: The Eureka Rapids and fish passage on the Eureka dam (From Bruch 2008)

5.1.2.2 Efficiency of fish passage use by sturgeon on the Fox River

This is a good example of mitigation of the impact of the Eureka dam on lake sturgeon migration. Lake sturgeon passage was recorded in the first year of operation of the fish pass and every subsequent year. Dam construction on sturgeon spawning and nursery rivers does not only block migration but can also significantly change habitats so that fragmented sectors of rivers can lose the available habitats. Construction of rapids and fish passage in this case also increased the available spawning area.

5.1.3 Trap-and-transport of lake sturgeon on the Winnipeg River

The Winnipeg River is 235 km long with its mouth at Lake Winnipeg. There are six hydroelectric dams on the Winnipeg River in Manitoba, of which the Seven Sisters is the largest producer of electricity. Lake sturgeon populations in the Winnipeg River have been seriously impacted by overfishing and habitat alterations.

5.1.3.1 Seven Sisters Generating Station dam

5.1.3.1.1 Location and dimension

The Seven Sisters Generating Station dam was built on the Winnipeg River at 72 rkm in two stages. The first stage commenced in 1929 and was completed in 1931, while the second stage was initiated in 1948 and finished in 1952. The dam is ~175 m long and the difference in water level is 18.6 m. As there are no existing fish passes on this dam, trap-and-transport was used to overcome blockage of migration by dam building.

5.1.3.1.2 Trap-and-transport

Trap- and-transport or trap-and-haul involves the active-manual (e.g., gill net) or passive-automatic (e.g., elevator) capture of fish downstream of the dam, followed by upstream relocation (McDougall et al. 2013).

5.1.3.1.3 Monitoring

One experiment included a catch of 6 female and 6 male lake sturgeon in pre-spawning conditions (fork length from 1.165 to 1.500 m) between May 22 and 26, 2009, in an area just downstream of the Seven Sisters GS (McDougall et al. 2013). The fish were fitted with acoustic transmitters and after transport in the tank they were released in the forebay 500 m upstream of the Seven Sisters GS. Receivers were installed 5.2, 10.3, 18.7 and 31.5 km upstream of the Seven Sisters GS, and a dual hydrophone was installed downstream of the dam (Figure 19). One tagged male of lake sturgeon was never recorded on any receiver while the other 11 lake sturgeon were recorded on upstream receivers in average 719 times. They all moved rapidly upstream and were registered on the 1st, 2nd and 3rd receivers while only one female and one male were recorded on the 4th receiver. This experiment showed that 11 tagged lake sturgeon

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within seven days of release were recorded by receivers located 18.7 km from the dam without fallback. They were resident in the area which is a known spawning site.

Three of the 11 tagged lake sturgeon made downstream migration to the Seven Sisters GS, but no downstream passage was recorded. However, many stations on the Winnipeg River were built on historical falls/rapids, which were likely barriers for sturgeon migration even in the past; it is therefore very important to take into consideration the specific aspects of the investigated areas (McDougall et al. 2013).

5.1.3.2 Efficiency of fish passage use by sturgeon on the Winnipeg River

This study confirmed that lake sturgeon are suitable for trap-and-transport as it is easy to catch, has a low mortality when fishing by gill nets, and exhibits rapid recovery from netting and handling stress. This experiment also showed that the sturgeon released in the reservoirs moved upstream and reached a known spawning site. In the case of trap-and-transport there is a problem associated with downstream migration when safe downstream migration is not provided. The only downstream passage for lake sturgeon on the Seven Sisters GS is the spillway gates which can be used only during high flow.

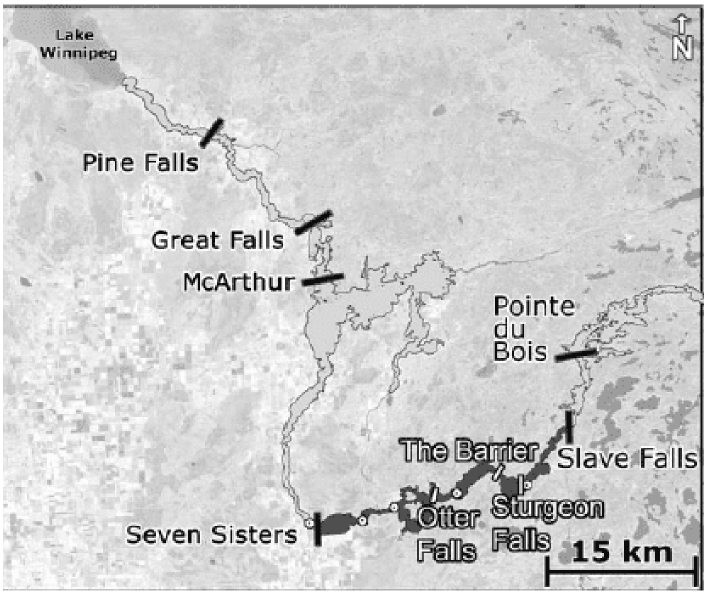

Figure 19: Six hydroelectric generating stations on Winnipeg River in Manitoba with the investigated area shown in grey, and Lotek receiver locations (white marker) (From McDougall et al. 2013)

5.1.4 Fish passage use by lake sturgeon on the Richelieu River

The Richelieu River originates in Vermont and New York (USA), and after exiting Lake Champlain it empties into the St. Lawrence River (Canada). The river is 124 km long with an average discharge of 362 m^3/s (Thiem et al. 2011). Historically, the Richelieu River was a key

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route of water transport for trade between Canada and the USA before the development of railways in the mid-19th century.

5.1.4.1 St. Ours dam

5.1.4.1.1 Location and dimension

The dam is 180 m wide and 3.4 m high, constructed for navigation purposes to maintain a stable water level upstream. It is situated 18 km upstream of the confluence of the Richelieu and St Lawrence rivers.

5.1.4.1.2 Passage facilities

The Vianney-Legendre is a vertical-slot fishway that was constructed in 2001. It is about 85 m long concrete structure with an elevation rise of 2.65 m and an average slope of 4%. The fishway has 18 pools in total: 12 regular rectangular pools (3.5 m long and 3 m wide), two resting/turning basins with curved walls – 2.75 m radius), entrance and exit pools, and 2 pools immediately downstream of the entrance pool (Figure 20). Pools have a 0.60 m wide vertical slot (2.30 to 4.00 m height range) with the head drop between consecutive pools of 0.15 m. Thirty-five different fish species pass through this fishway. Priority fish species for its construction were Cooper redhorse, lake sturgeon, American shad and American eel.

5.1.4.1.3 Monitoring

An experiment was designed to establish the percentage of successful passage for lake sturgeon on this fishway. To that end, 107 lake sturgeon (having a mean total length of 1213 mm and weight of 10.4 kg) were captured from 11-25 May 2010 about 700 m downstream of the dam (Thiem et al. 2011). All fish were tagged with a uniquely coded PIT tag and detection was performed by a PIT array consisting of 16 antennas (Figure 201). Results showed that 88 of 107 specimens attempted to pass the fishway (82.2%), and that 32 made a successful ascent (29.9%). Overall passage efficiency was calculated as the number of successful passages related to the number of individuals that attempted to pass the fishway, which was on average 36.4% (from 27.3-47.4%); no relationship between water temperature or fish length and passage speed, passage success or maximum upstream distance was found, even though such a relationship was found for lake sturgeon in the laboratory. Sturgeons experienced difficulties while passing through the turning basins.

Lake sturgeon displayed different behaviours when attempting to pass the fishway, with some making a single attempt and failing to pass, multiple attempts and failing to pass, or a single attempt and a successful pass, as well as multiple attempts and a successful pass. Passage failure mostly occurred in the downstream half of the fishway, and most fish passed if they reached the second half of the fishway. The average time for successful passage was 27.38 h (ranging from 6.19 to 75.38 h). The time that lake sturgeon spent in the turning basins was longer than in other basins regardless of whether passage was successful or unsuccessful.

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Turning basins could be replaced by benthic station holding for recovery of sturgeon after burst swimming.

This study showed that there are individual differences in passage performance but that it was not possible to obtain an answer regarding the dependence of fish behaviour on the fine scale of the hydraulic conditions in a particular pool. Endogenous factors can also contribute to differences in fish passage efficiency. Investigations in the same fishway using triaxial accelerometers (Figure 20) for estimating energy expenditure for the fish pass showed that high-speed swimming occurred rarely and for a short time, and that the turning basins delay the passage at a larger energetic cost. The energy cost of lake sturgeon passage through the fishway is 883-5540 J kg-1, which is equivalent to a sturgeon traveling 2.1-13.3 km in a lentic system (Thiem et al. 2016).

5.1.4.2 Efficiency of fish passage use by sturgeon on Richelieu River

The St. Ours dam has one of the few efficient fishway for sturgeon. Of all tagged sturgeons, 82.2% attempted to pass the fishway, 29.9% had a successful ascent with an overall passage efficiency of 36.4%. It was also demonstrated that the turning basin impeded progress of lake sturgeon ascent in the fishway.

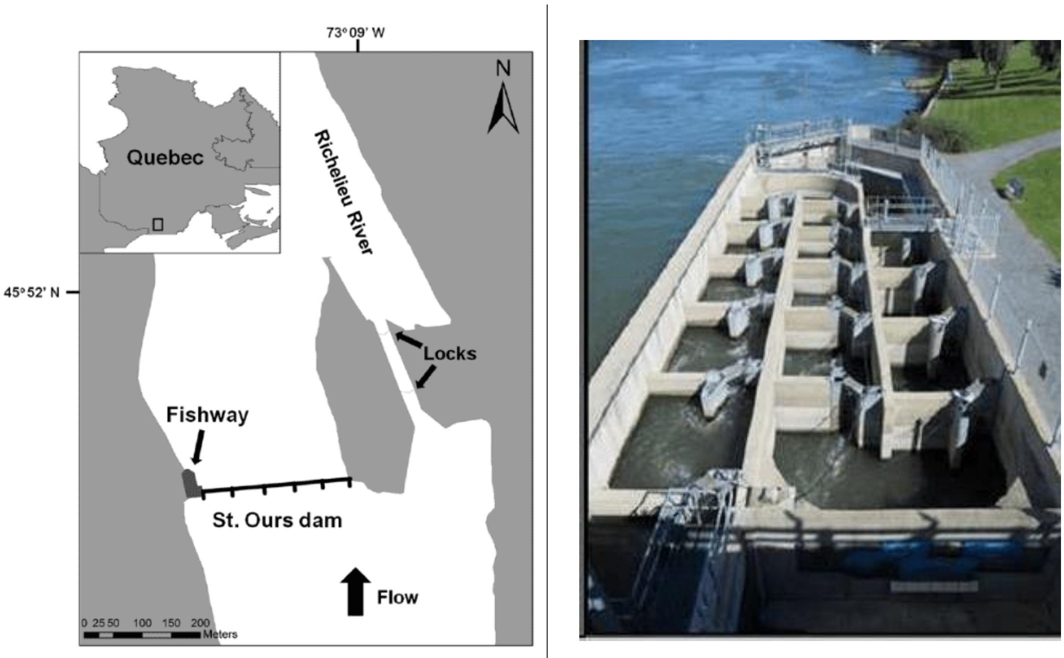

Figure 20: Position of the fish pass on St. Ours dam and a photograph of the fish pass (From Thiem 2013)

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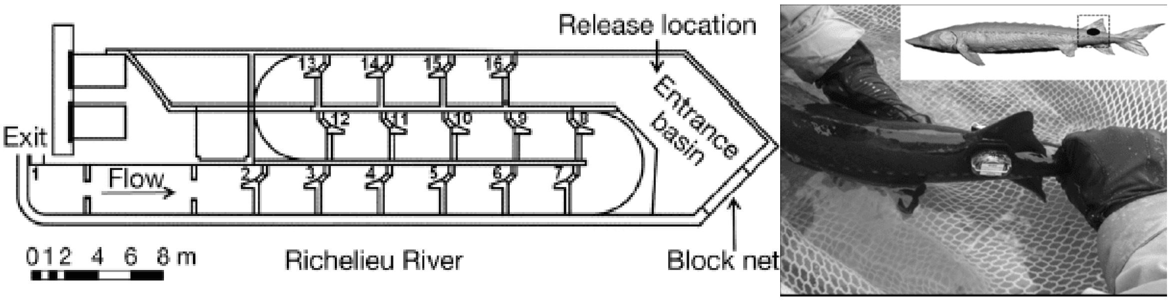

Figure 21: Schematic diagram of the fishway with numbers indicating the antennas and accelerometer mounted on a lake sturgeon (From Thiem 2013)

5.1.5 Fish passage use by lake sturgeon on the Eastmain River

The Eastmain River is 756 km long, it springs in central Quebec and flows west to James Bay. A 25-km- long sector of the Eastmain River downstream of the Eastmain-1 dam before its construction was inhabited by lake sturgeon with recorded feeding, spawning and wintering habitats.

5.1.5.1 Eastamin-1 hydroelectric dam

5.1.5.1.1 Location and dimension

The Eastmain-1 hydroelectric dam was constructed on the Eastmain River in mid-northern Quebec (Canada) from 2002 to 2006.

5.1.5.1.2 Passage facilities

The weir and fish pass were constructed in 2005-2006 as compensation for the environmental impact on fish 10 km downstream of the dam (Figure 22), with the aim of maintaining water level and fish access to feeding and wintering habitats (D'Amours et al. 2019). Additionally, two artificial spawning grounds were created in 2004 and 2006 upstream of the weir and downstream of Eastmain 1 dam. Before construction of the Eastamin-1 dam, the main spawning location for lake sturgeon was 2 km downstream of the current dam, which rendered unusable after dam construction due to daily variations in flow velocity and water levels. The multispecies fish pass is a pool-weir type (17 weirs, each step 0.15 m) with a length of 150 m and a width of 15 m. Spacing between weirs is 8 m, slot width 0.5 m to insure passage of large specimens. Positioning of the slot alternates from wall to wall to create eddies.

5.1.5.1.3 Monitoring

Monitoring of the fish pass was performed during the period from 2007-2016 with relevant data collected for lake sturgeon, walleye, lake whitefish (*Coregonus clupeaformis*), northern pike (*Esox Lucius*) and suckers (*Catastomus* spp.). Monitoring of the fish pass through the fishway showed that a flow velocity of 2 m/s was too high for fish, leading to additional work

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in 2008 to reduce the flow velocities to 1 and 1.4 m/s. The highest number of lake sturgeon specimens was detected in the fish pass in June during their spawning migration. Monitoring also confirmed successful spawning of lake sturgeon downstream of the fish pass and inside the fish pass. A total of 304 lake sturgeon was PIT-tagged, and monitoring during 2009- 2016 showed that the migration success rates for juvenile and adult lake sturgeons through the fish pass gradually increased and reached 80% in 2016 (D'Amours et al. 2019).

5.1.5.2 Efficiency of fish passage use by sturgeon on the Eastmain River

The fish pass showed higher efficiency after the adjustment of the flow velocity. Also, monitoring confirmed successful spawning of lake sturgeon inside the fish pass and downstream of it. Lake sturgeon were mostly detected in the fish pass in June during the spawning period of this species. Successful upstream migration was performed by both juvenile and adult lake sturgeon. Migration success was gradually increased with values of 29%, 37% and 80% in 2014, 2015 and 2016, respectively.

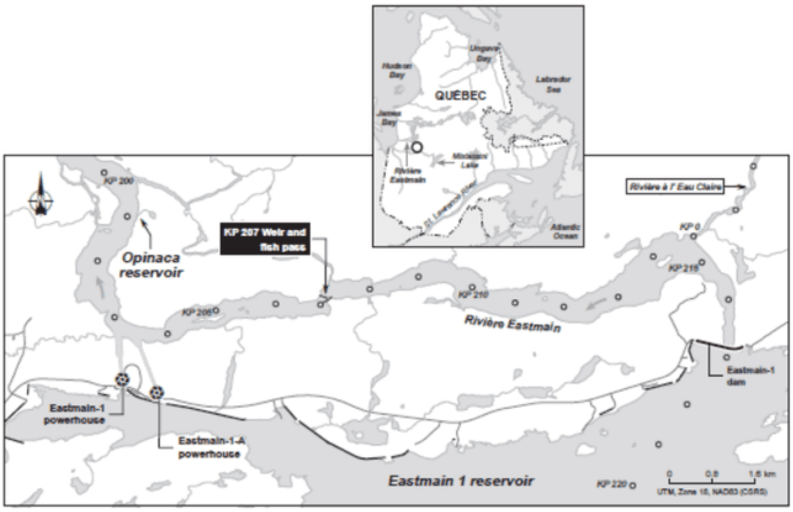

Figure 22: The Eastmain River with its tributary, Rivière à l'Eau Claire, Eastamain-1 dam, and additional Eastamin-1 and Eastamin-1A powerhouse, KP 215 – the main spawning ground for lake sturgeon before dam building, KP 207 – the weir and fish pass (From D'Amours et al. 2019)

5.2 Fish passage facilities and their utilization by white sturgeons (*Acipenser transmontanus*)

5.2.1 Fish passage facilities for white sturgeon on the Columbia River

The Columbia River, with a length of 2,000 km, is the fourth largest river in the US by volume with the greatest flow of any North American river entering the Pacific. Construction of hydroelectric dams on the Columbia River highly impacted white sturgeon, which resulted in several individual landlocked populations. The first dam from the mouth of the Columbia River is Bonneville dam lying at 235 rkm, upstream is Dalles dam at 309 rkm, and 36 km upstream is the John Day dam located (Figure 23). The construction of dams in the Columbia River basin has

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led to the creation of 24 functionally discreet populations of white sturgeon. The largest population in the Columbia River is inhabiting the lowest river section downstream of Bonneville dam

5.2.1.1 Bonneville dam

5.2.1.1.1 Location and Dimension

The Bonneville dam was built in 1934 and it is located on the Columbia River at rkm 235. The length of the dam is 820 m and the height is 60 m.

Figure 23: Lower Columbia River with the Bonneville (BON), Dalles (TDA) and John Day (JDA) dams (Wills 2014)

5.2.1.1.2 Passage facilities

Originally, there were three locations designed for fishways in 1937, one on each end of the spillway dam which was on the north side of the Columbia River in that time and one at the powerhouse on the Oregon side. Each of this fishway was composed of a collecting system, a fish ladder, and a pair of fish-locks. There was a possibility for fish ladders and fish-locks to operate simultaneously or separately. Fish locks are still in place but has not been used since 1971. Nowadays, the Bonneville dam has 8 entrances to 3 fish ladders and 2 powerhouse collection channels (Figure 24). Fish ladders are designed for adult anadromous salmonids. A vertical distance which fish have to negotiate is 13.7-21.3 m depending upon the time of year and river conditions. Attraction velocity is 2.4-3.0 m/s. The main ladder sections are typically pools with weirs having overflows, and submerged orifices. Target velocities for the orifices and overflows are 2.4 m/s for salmon passage. The typical ladder slope is 6.25%.

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5.2.1.1.3 Monitoring

During fish lock operation, white sturgeon passed upstream, but their number was typically low except for one time in 1951 when during a single day 119 white sturgeon passed. During the period between 1938 and 1969 when two fish ladders and locks were operating, the vast majority of sturgeon (97%) passed the dam via the fish lock (Wittmann-Todd et al. 2003). Two hundred and fifteen white sturgeons were counted at Bonneville fish ladders during the period 1986-1991 (19-60 annually).

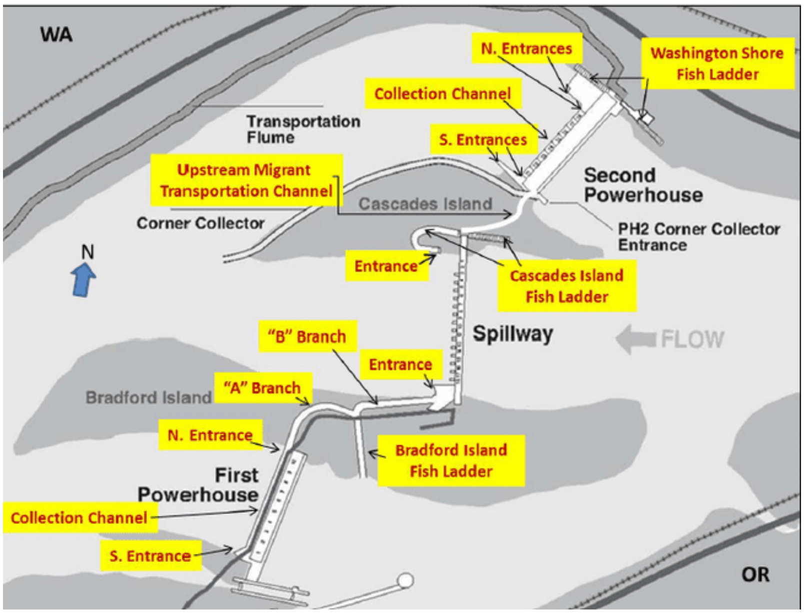

Figure 24: Overview of Bonneville dam and upstream fishways (Wills and Anglin 2012)

5.2.1.2 Dalles dam

5.2.1.2.1 Location and Dimension

The hydroelectric power dam Dalles was constructed in the period from 1952-1957, and is 2.4 km long with a head of 24.4 m.

5.2.1.2.2 Passage facilities

There are two fishways (represented by overflow weir ladders with orifices) for upstream migration designed primarily for anadromous salmonids (**Fehler! Verweisquelle konnte nicht gefunden werden.**, Figure 25). The north ladder has one entrance and the east ladder has three separate entrances. A water velocity of 0.5-1.2 m/s is maintaining in the collection channels and lower portion of both ladders. The ladders are in function throughout the year except for a few weeks in December, January or February.

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Table 8: General characteristics of adult fish ladders at the Dalles dam (Parsley et al. 2006)

	Fishway	
	East	North
Ladder length	540 m	540 m
Ladder width	9.14 m	7.32 m
Mean slope	4.4 %	4.4 %
Number of weirs	89	90
Weir spacing	4.67-4.88 m	4.27-4.88 m
Weir configuration	Weirs 1 through 89 – overflow with 2 orifices	Weirs 1 through 82 - overflow with 2 orifices Weirs 83 through 90 – non-overflow with 1 orifice and 1 vertical slot
Weir orifice size	0.64 m W x 0.66 m H	0.46 m W x 0.46 m H
Weir vertical slot width	none	0.30 m

Downstream migration is possible through spill gates, the turbine, ice and trash sluice way and the navigation lock.

5.2.1.2.3 Monitoring

In the period from March 2004 to November 2005, investigations were performed on 148 individuals of white sturgeon (Figure 26). Fifty-eight white sturgeon individuals were caught and released in the forebay and 90 were caught and released in the tailrace. The total length of tagged white sturgeon was in the range of 95-280 cm. During the investigated period, 26 passage events were recorded with 19 tagged fish, of which 8 were upstream and 18 were downstream (Parsley et al. 2007). Eleven passage events were made by only 4 fish, which means that they made both upstream and downstream passages during the period of investigation. Residence time within fish passage facilities was from about 1 minute to nearly 6 months (mean = 7.1 days; SD = 24.8 days) and it was shorter in 2005 (mean = 0.9 days) than in 2004 (mean = 8.63 days). This investigation showed that white sturgeon mainly used the east ladder for upstream migration, which could be explained by the difference in construction of these two ladders, both of which are longer than 500 m and are of the pool and weir type with submerged orifices: the north ladder is narrower than the east and has a smaller cross-section area of orifices (0.21 m2) than the east ladder (0.42 m2). Also, the east ladder has no vertical slot and has three entrances to the fishway. The success rate for white sturgeon pass was 41.2%. Downstream migration was performed mainly through open spillway gates and probably smaller sturgeon could pass downstream through the turbines at any time of the year. At least 10 of 12 downstream passage events were through open spillway gates. Use of the navigation lock by white sturgeon has not been confirmed (Parsley et al. 2007).

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Figure 25 : The Dalles dam with north and east fish ladders (Parsley et al. 2006)

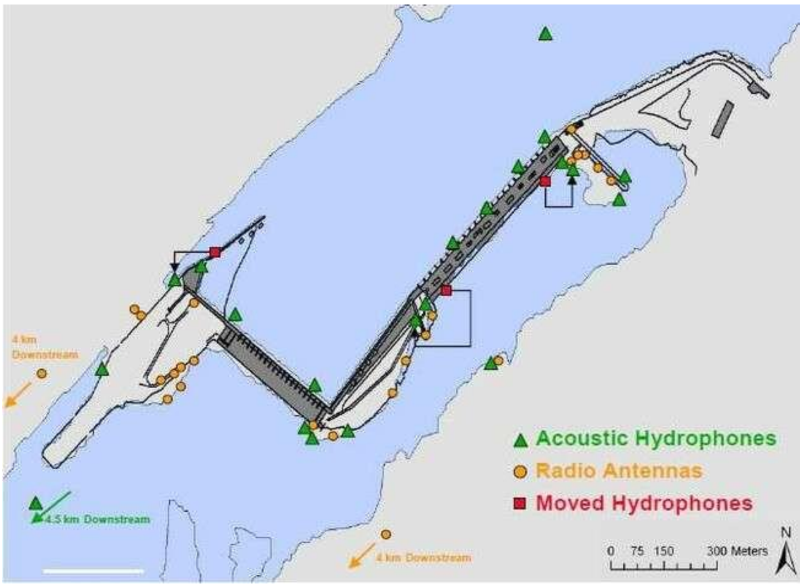

Figure 26: Position of acoustic receivers and radio antennas around the Dalles dam in 2005 (Parsley et al. 2006)

5.2.1.3 John Day dam

5.2.1.3.1 Location and Dimension

The John Day dam was authorized for flood control, power, and navigation purposes in 1950. It is constructed on the Columbia River at rkm 3455. The length of the dam is 2,327 m and the height is 56 m.

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5.2.1.3.2 Passage facilities

Fish passage facilities comprise two fish ladders on the north and south side of the dam, (Figure 27). As in the case of the Bonneville and Dalles dams, anadromous salmonids were the target species for these ladders. In a typical year during the fish passage season the vertical ladder elevation change is about 30.8-31.1m that fish must negotiate. John Day Dam has entrance that lead to a powerhouse collection channel, entrance to south fish ladder and entrance to north fish ladder (Figure 27). Velocity at the entrance to powerhouse collection channel is in range 2.4-2.7 m/s as well as at the entrance of south and north fish ladder, and 0.4-1.2 m/s in the channel. South fish ladder composed of entrance, junction pool, ladder section 1, count window, ladder section 2, turning pool 1, ladder section 3, flow control and exit near the south end of the powerhouse. North fish ladder composed of entrance, ladder section 1, turning pool 1, ladder section 2, turning pool 2, ladder section 3, turning pool 3, ladder section 4, turning pool 4, ladder section 5, count window, flow control and exit near the navigation lock.

5.2.1.3.3 Monitoring

Investigations during the period 1986-1991 recorded 3,181 white sturgeon specimens (187-791 fish per year) at the two fishways on the Dalles dam. During the same period, 215 white sturgeon (19-60 annually) were counted at Bonneville dam fishways and only 68 (4-29 annual range) at the John Day dam (Warren and Beckman 1993, cited in Parsley et al. 2007).

Figure 27: The John Day dam (Wills 2014)

5.2.1.4 Efficiency of fish passage use by sturgeon on the Columbia River

Practices of fish passage on the Bonneville dam showed that sturgeon used fish lock more frequently than ladders for upstream migration. It was also revealed that sturgeon use of ladders is highly variable among dams, although they have similar designs (Wittmann-Todd et al. 2003). Investigation of two fish ladders on Dalles dam by telemetry is one of a few cases relating to the efficiency of fish passages for sturgeons performed in the field; sturgeons

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mainly used the east ladder for passage as it is 1.8 m wider than the north ladder, and submerged orifices have a two-fold larger surface area of orifices (Parsley et al. 2007).

5.3 Fish passage facilities and their utilization by shortnose sturgeon (*Acipenser brevirostrum*)

5.3.1 Fish passage facilities for shortnose sturgeon on the Connecticut River

The Connecticut River is 653 km long and discharges at the Long Island Sound to the Atlantic Ocean. It is among the most extensively dammed rivers in the USA with the first dam constructed as early as 1798 for barge/boat movement. The Connecticut River watershed has more than 3,000 dams with a significant impact on migratory fish species.

5.3.1.1 Holyoke dam

5.3.1.1.1 Location and Dimension

The Holyoke dam was built on the Connecticut River in 1849 at river kilometre 140, and there is no downstream dam. The hydropower station began operations in the 1950s. The length of the dam is 310 m and the height is 10 m. The license issued by the Federal Energy Regulatory Commission required the construction of fish passage facilities on this dam (Kynard 2008).

5.3.1.1.2 Passage facilities

Construction of a tailrace lift that was completed in the mid-1950s attracted fish by discharge of the hydroelectric turbine, and a spillway lift that was constructed in 1976 attracted fish by spilling water over the dam. Fish passage was constructed for target species, Atlantic salmon (*Salmo salar*) and American shad (*Alosa sapidissima*) (Kynard 2008). Two lifts on Holyoke dam are in function during spring (late April-mid July) and autumn (September, October). Shortnose sturgeon inhabits the lower and middle reaches of the Connecticut River, and at the start of fish lift functioning it was not a target species. Downstream fish passage facility is presented by the canal system and full-depth louver arrays which guide fish to a discharge pipe that transports downstream migrating fish to the tailrace of Holyoke Dam.

5.3.1.1.3 Monitoring

The passing of shortnose sturgeon in fish lifts was analysed, and is based on data collected during a 22-year period (1975-1996). Data included the number of successful passages of shortnose sturgeon via two lifts, the yearly and monthly trends in fish passage, daily timing, as well as data about water temperature and water discharge (Kynard 1998). During the period of 22 years, 97 shortnose sturgeons were lifted, most of them individually during daylight. The proportion of fish that passes annually through fish lifts is only a small percentage of fish present at the dam. Most of the shortnose sturgeon were lifted when the water temperature was between 12 and 23°C (Kynard 1998). During the observation period, 97 shortnose sturgeons were lifted, most of them individually during daylight at water temperatures between 12 and 23°C (Kynard 1998). The increase in water discharge triggers

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fish migration upstream towards the dam, thus attraction and lifting should take place during 10 days of high river discharge. The physical conditions of the entrance of the spillway and the tailrace fish lift are quite different and most migrating fish used the spillway lift. Because of this, the spillway lift was a priority to improve the passage for shortnose sturgeon which resulted in improved conditions for the passage of shortnose sturgeon during the last three years (2016-2018). In 2015 improvements included the addition of a flow deflector to make it easier for fish to find their way to the lift entrance, as well as increased water velocity. In accordance with the Annual Progress Report (2017-2018) for the Connecticut River, the shortnose sturgeon is under recovery and designated as a federally endangered species that needs continual monitoring, study and protection (Anonymous 2018).

The Holyoke dam is also a very good example of an improved downstream passage and protection of adult shortnose sturgeon and American eel by use of new engineering approaches.

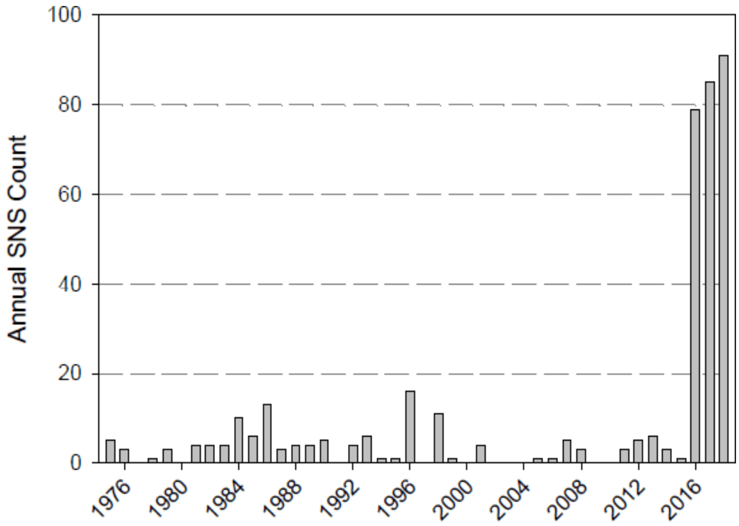

Figure 28: Number of shortnose sturgeon specimens trapped annually at the Holyoke fish lift in the period 1975-2018 (From Anonymous 2018)

5.3.1.2 Efficiency of fish passage use by shortnose sturgeon on the Connecticut River

For the first time after many years, 87 specimens were counted at the fishway in 2017 (Figure 28). During fishway operations in the period from April 24 through October 30, 2018 (119 days of operational lifting and 71 non-lifting dates), a total of 91 shortnose sturgeon specimens were trapped at the Holyoke fish lift. During this period, three mortalities of shortnose sturgeon were documented, and in one case corrective measures were developed in order to avoid such injury in the future.

The passage efficiency for sturgeons was significantly improved on the Holyoke dam after engineering works with an increase in sturgeon individuals trapped at the Holyoke fish lift

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recorded during 2016-2018. Also, corrective measures were implemented to decrease the possibility of sturgeon injury or mortality during passage. These two fish lifts are among the most successful facilities for fish passage on the Atlantic coast of North America, with 500,000 - 1,000,000 specimens of diadromous fish passing annually. The Holyoke dam fish pass represents a good example of a fish pass for different anadromous fish species such as Atlantic salmon, American shad, blueback herring (*Alosa aestivalis*), alewife herring (*Alosa pseudoharengus*) and shortnose sturgeon (Figure 29). Monitoring of the efficiency of fish lifts and their improvements is a part of a federal project related to Connecticut River basin anadromous fish restoration, which includes the organization and documentation of activities concerned with the improvement of the status of anadromous fish species (investigation of fish populations, habitats, restocking activities).

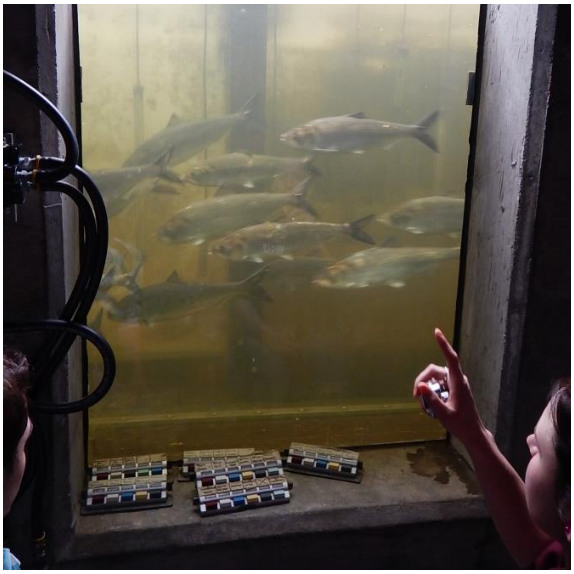

Figure 29: Holyoke fish lift staff counting fish (From Anonymous 2018)

5.3.2 Possibility for shortnose sturgeon passage by navigation lock on the Cooper River

The Cooper River is one of the most historically significant rivers in South Carolina (it served as a main transportation route during the colonial period), and its estuary unites with the Ashley River to form Charleston Harbour on the Atlantic Ocean. It has long use as an important commercial waterway.

5.3.2.1 Pinopolis hydroelectric dam

5.3.2.1.1 Location and Dimension

The Pinopolis hydroelectric dam was built in 1941 on the Cooper River at 77 rkm. The dam is 42 m high and 3,500 m long.

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5.3.2.1.2 Passage facilities

It possesses the highest single-lift navigation lock in the world, which is 18 m wide, 73 m long, with a lift of about 22 m. This navigation lock has been used successfully for upstream passage of *Alosa* spp. from the 1970s.

5.3.2.1.3 Monitoring

Investigation of shortnose sturgeon, which utilizes the tailrace, was performed in the 1990s. About 200 fish utilized the tailrace but it is unknown if shortnose sturgeon used the navigation lock for passage. Radio telemetry was used to record the movements of 48 individuals with internally-implanted transmitters and 24 individuals with externally-attached transmitters (Cooke et al. 2002). The mean total length of the tagged specimens was 982 mm, with a mean weight of 8.58 kg. Sturgeon catch was performed during January, February or March from 1995 to 1999. The antennas for signal reception were located to cover the area in the tailrace, within the navigation lock, and at the exit of the navigation lock on the lakeside (Figure 30). Mobile tracking was conducted once a week to determine when tagged fish left the area under the study. Internally-tagged sturgeons were detected after release in the tailrace for 31 days. One year after release, 50% of the tagged fish returned to the tailrace with a residence time of 13 days. The navigation lock was not in operation during 1998. It operates during March four times a day (at 7:00 am, 11:00 am, 3:00 pm and 6:00 pm). Between operations the downstream gates were partially opened to form a "V-trap". Twenty-seven (55%) of the 49 tagged fish that remained had made 192 entries into the navigation lock, entering as early as 27 February and up to 3 April. Seven fish were in the lock through a locking cycle with the possibility to pass into the lake, but there are no records of fish on the lakeside of the lock (Cooke et al. 2002). This study showed that shortnose sturgeon entered the navigation lock more often at night than during the day. There are different reasons why the shortnose sturgeon did not pass, which include rapid filling of the lock with water which causes turbulence and disorientation of fish, and because the fish must swim upwards for about 15 m from the bottom in order to exit the lock in a short time (10-20 min) at the upstream gate-opening. A problem could be also that there is no current or water flow to guide the fish through the lock when the upper gates open (Cooke et al. 2002). Another problem is downstream migration. As it is not a problem for *Alosa* spp., which is mostly semelparous, it could be a problem for short sturgeon, which is iteroparous. Juvenile fish could pass downstream through turbines with a small mortality but adults require bypass facilities.

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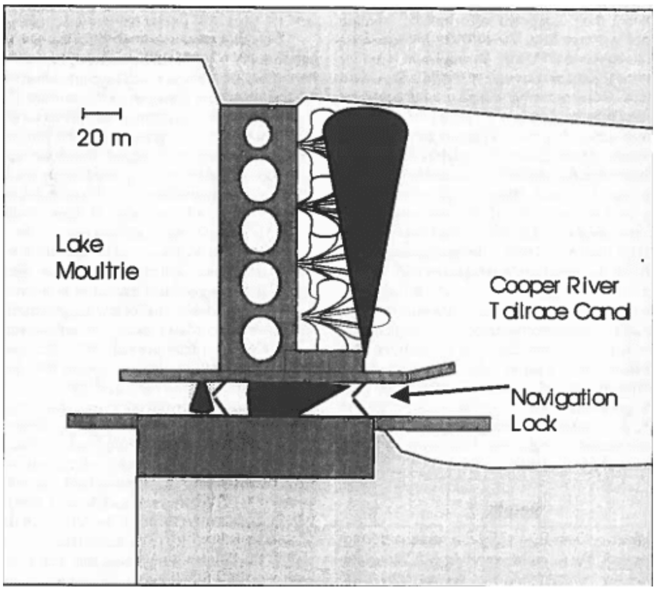

Figure 30: Antenna coverage (cones) at the Pinopolis dam at the tailrace within the navigation lock and at the exit from the navigation lock (From Cooke et al. 2002)

Additional investigations at the Pinopolis dam were performed on two individuals of shortnose sturgeon (1,022 mm, and 935 mm total lengths), which were caught at the tailrace and tagged on February 20, 2002 (Finney et al. 2006). After implantation of transmitters, they were transported upstream and released in Lake Moultrie, 5 km north of the Pinopolis dam. After release, they were tracked daily by boat or semi-monthly by air. Both fish travelled 161 rkm in two weeks (traversing Lake Moultrie, Lake Marion and the Congaree River), and remained at that location for at least 14 days (Figure 31). This location is characterized by gravel deposit but spawning activities were not documented. They travelled 22.4 km/day during upstream migration. At the end of March, both fish migrated downstream and reached an area of rapids at the confluence of the Santee River and Lake Marion. This showed that shortnose sturgeon attempted to find their historical spawning place (Finney et al. 2006).

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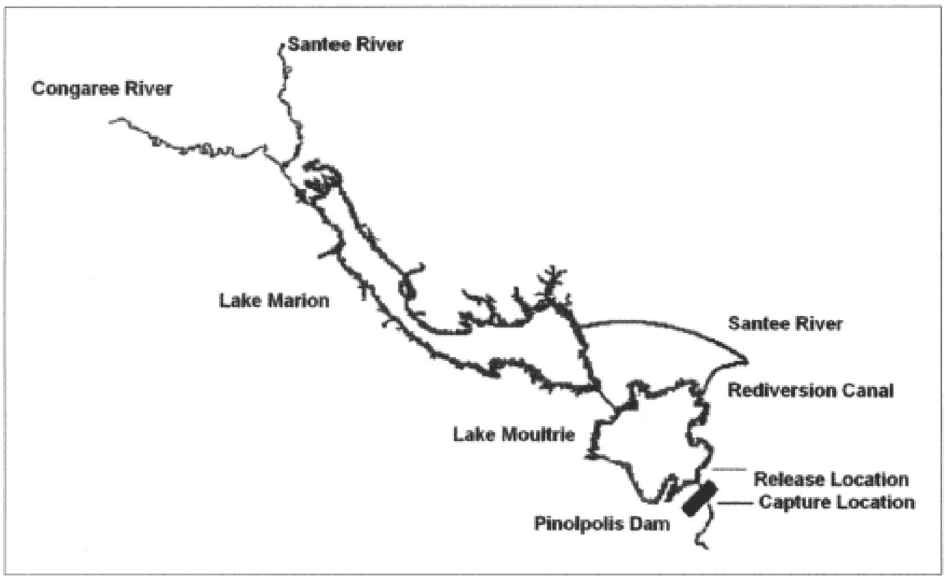

Figure 31: The Santee-Cooper System where upstream and downstream migrations of shortnose sturgeon were monitored. The fish rapidly traversed 161 km and navigated through the relatively still waters of Lakes Moultrie and Marion to reach the area where shortnose sturgeon spawning was previously documented (From Finney et al. 2006)

5.3.2.2 Efficiency of of shortnose sturgeon passage by navigation lock on the Cooper River

Investigation at the navigation lock at the Pinopolis dam showed that the lock was unsuitable for sturgeon passage but that some techniques could increase passage, such as (i) instating a slowly-filling lock to minimize turbulence and sturgeon disorientation; (ii) creating a guiding flow through the lock after opening of the upper gates; (3) leaving the upper gates open for a longer time to enable sturgeon to locate the exit. Other structural modifications could be used to encourage the fish to exit the lock.

5.4 Efficiency of fish passage use by sturgeon in the USA & Canada

Examination of the efficiency of sturgeon usage of different fish passes in the USA and Canada included investigations performed on fish lifts, ladders and other different types of fishways, as well as investigation of the likelihood of navigation lock use for passage by sturgeon. Experiments and field studies were performed on three sturgeon species: lake sturgeon, shortnose sturgeon and white sturgeon. When a lift is used for sturgeon passage it is important to time seasonal and diurnal lift operations to match sturgeon migrations (Jager et al. 2016). Construction of the fish lift on the Menominee hydroelectric dam in 2015, 90 years after the dam was built in 1925, showed good results regarding the number of lake sturgeon that could overcome the obstacle. Modification of the lift-operation procedure, mainly during evening and night hours with longer soak periods and at higher attraction flow, resulted in better efficiency of lake sturgeon passage. Telemetry investigation of the use of ladders for sturgeon pass revealed that sturgeon prefer wide ladders with large and/or submerged orifices. Also, turning basins cause a delay in passage and a greater energetic cost. Use of the

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navigation lock for sturgeon passage was unsuccessful and substantial change is suggested to achieve the passage of sturgeon through a ship lock.

Monitoring of the efficiency of fish passes and their improvements is a part of projects related to sturgeon restoration. These projects also include the study of sturgeon populations, the status of spawning, wintering and nursery habitats, as well as restocking activities.

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6 ADAPTIVE RECONNECTION AS A STRATEGY FOR BUILDING AN EFFICIENT FISH PASS

Specific areas and dams require specific approaches in solving fish pass problems. The building of fish passes should be done in a way that allows easy modification in cases where it is necessary to improve performance. The building of fish passes also needs the development of strategies for a continual science- based process of experimentation and monitoring (Jager et al. 2016). Holyoke dam represents a good example of increasing the efficiency of fish passage through modifications, and in 2015 improvement included the addition of a flow deflector to make it easier for fish to find their way to the lift entrance, as well as increased water velocity. In this sense, it is very important to test in the field laboratory-derived swimming models. The main improvements for upstream migration could be achieved with fish guidance to approach/discover the entrance to the fish passage, to enter the fishway, to pass through it and safely exit. Investigation carried out at the fishway on St. Ours dam on the Richelieu River is the first attempt to quantify the behaviour of sturgeon during passage, and has provided valuable data concerning future design of fish passes for sturgeon. One of the biggest problems is a lack of evaluation of the efficiency of fish passage structures for many years after their use. Nowadays telemetry represents a valuable method for evaluating the efficiency of fishways. The first evaluation of fishway efficiency included only a qualitative description of the fish passage and quantitative measuring of swimming performance, mainly in laboratory conditions. The efficiency of fish passes depends on the efficiency of three processes: approach, entry and passage, and the proportion of fish moving from one to the other process needs to be determined. On the basis of continual and standardized monitoring of fish passes alone, is it possible to organize a valuable database that could be used as guidance for designing and constructing a new fish pass. Bunt et al. (2012) identified more than 100 papers dealing with the evaluation of fish pass efficiency, but only 19 of them provided sufficient data to determine the proportion of fish entering and passing through a particular fish pass. Among the 19 cases there were different types of fish passes and different fish species (no sturgeon species were investigated), which made it impossible for the authors to support any fish pass design as being more efficient. Pandit et al. (2016) showed that passage design criteria for effective up- and downstream migration for sturgeon are still not well established.

Aside from monitoring individual fish passes, it is very important to set as the main goal the monitoring of the impact on fish populations and the recovery of populations, especially of endangered fish species. Sometimes sturgeons move upstream into an “ecological trap”, as in case when reservoirs have periods of high-water temperature and low dissolved oxygen, which happened in a low-flow year in the Snake River reservoir when the anoxic conditions contributed to the mortality of 28 white sturgeon (Jager et al. 2016). It is important to monitor in-river long-distance movement to the spawning grounds and the success and timing of downstream migration. Passage effectiveness should be considered broadly and include population biology (reproductive biology, genetics) and the possibility of access to spawning, nursery and feeding habitats (Silva et al. 2018). Fish pass science nowadays involves different disciplines, such as fish behaviour, socioeconomics, and modelling of passage prioritization

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options in river networks (Silva et al. 2018). The building of new fish passes and evaluation of the efficiency of existing structures needs substantial budgets. Castro-Santos and Perry (2012) reported that USA government agencies and utilities spend more than $80 million annually for building and evaluating structures in order to improve the survival and passage of migratory fish species with the use of acoustic and radio telemetry as well as passive integrated transponder (PIT) telemetry to assess the efficiency of fishways.

Analysis of the available data concerning passage success on particular dams in North America showed that of the nine existing sturgeon species there were only examples of passage success for three species: shortnose sturgeon, lake sturgeon and white sturgeon (Jager et al. 2016), and that the highest number of investigations were performed on lake sturgeon. Investigations of the efficiency of fish passages in Russia were performed mainly for beluga, Russian and stellate sturgeon as well as for sterlet. Telemetry was used for investigating sturgeon behaviour in Russia but data concerning the efficiency of fish passes are mainly related to the efficiency of sturgeons to pass two successive dams (the Volgogradskiy and Saratovskiy dams on the Volga River, or the Fedorovskiy and Krasnodarskiy dams on the Kuban River). There are some data concerning spawning, nursery and feeding habitats along the Don, Kuban and Volga rivers, but during more than 20 years there was no tagging and monitoring of fish after their passage (Pavlov and Skorobogatov 2014). Pavlov and Skorobogatov (2014) also mentioned that urgent modification and reconstruction of existing structures are needed. Recently, certain technical improvements to the Krasnodarskiy fish lift have increased the number of fish passing via the lift. Significant illegal fishing and insufficient protection of fish resources in Russia have drastically reduced the number of fish approaching and entering fishways, especially sturgeon.

Jager et al. (2016) have summarized the lessons learned from past experience that could help in the design of new facilities for sturgeon passage. They are mainly related to suggestions for structures for downstream passage that could be extended to the riverbed, and for the opening of spillways to allow larger sturgeons to pass. Also, investigations showed that higher attraction flows that can be detected by sturgeon traveling in the thalweg are needed. A study of white sturgeon passage at the Dallas dam showed that wide ladders with large orifices are preferable (Parsley et al. (2007). Bruch (2008) reported that fishways with low gradient structures (less than 5%), which are represented by nature-like fishways with wide pools that do not require jumping, are effective for sturgeon passage. Experience has also shown that the filling of lifts should be slowed down in order to minimize turbulence, and that the operation of lifts should be based on sturgeon migration. Exit from fish passes could be located away from the turbine intakes to avoid entrainment of sturgeon. In some cases, trap-and-transport could be used for sturgeon translocation, which is possible to do in tanks with water taken from the collection site and with light oxygenation.

There have been some recent investigations on the efficiency of fish passes used by sturgeon that could be added to this list, and it is important to regularly update the list with new findings. In this way, guidance for the design and construction of efficient fish passes for sturgeon could be developed.

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7 EXPERIENCE IN EUROPE CONCERNING THE USE OF FISHWAYS BY STURGEONS

There is insufficient knowledge of sturgeon fish passage in Europe. Currently, there are two Horizon 2020 projects in Europe concerning fish passage: Fishfriendly Innovative Technologies for Hydropower (FIThydro) and AMBER (Adaptive Management of Barriers in European Rivers), with project duration from 2016-2020.

AMBER examines innovative solutions to river fragmentation in Europe by developing more efficient methods of restoring stream connectivity through adaptive barrier management, and in part it also deals with fishways.

The main aim of FIThydro is to develop efficient cost-effective environmental solutions to avoid fish damage by hydro power plants (HPPs) and to support the development of self-sustaining fish populations. The impact of HPPs as migration barriers on different fish species was scored for 148 European fish and lamprey species on mortality, primarily during fish passage through turbines and as the outcome of habitat loss due to impoundment. Based on this classification, all sturgeon species are classified into a group containing 18 species with "highest sensitivity" (Wolter et al. 2018). In the framework of FIThydro, a state-of-the-art identification of knowledge gaps and required research was performed by reviewing the solutions, methods, devices and tools to restore upstream and downstream fish migration, which included existing data concerning sturgeons (Dewitte et al. 2018). The final results of FIThydro will be used for organization of the Decision Support System, which will enable operators to fulfil the requirements of cost-effective production and to meet environmental obligations, as well as to acquire a self-sustained fish population.

The only fish passage facility in Europe where sturgeon was a target species is on the Elbe River. It was constructed on a weir situated 123 km upstream from the river mouth. The weir was constructed in 1961 and blocked the passage of migratory fishes. The first fish pass was built as a side channel in the 1990s, however, the hydrological conditions did not allow large-scale migration through the fishway. New fish passage facilities were constructed in 2010 and consist of a 500-m-long and 11-m-wide double-slot pool- pass where sturgeon is the target fish species (with sturgeon of 3.5 m as the reference for the layout and hydrology), containing 16-m-long, 9-m-wide and 1.75-m-deep pools with a 0.10-m drop between them (Comoglio 2011, Williot et al. 2011). During the planning of the double-slot pass on the weir structure in Geesthacht, ethohydraulic studies on the passage behaviour of fish were conducted, with sturgeon included as test fish. After construction of the fish pass, two Siberian sturgeon were recorded in the double-slot pass in 2011, and four were observed in 2012. The facility is also adapted for a whole spectrum of fish species in the Elbe River and it represents the largest European fish pass.

The Iron Gates I and II have been in operation from 1972 and 1984, respectively. They constitute the largest hydropower, dam and reservoir system along the Danube River, and are jointly operated by Romania and Serbia. Fish passes were not constructed on these dams and as

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compensation for the blocking of fish migration, a sturgeon hatchery was built in the vicinity of Iron Gate I, but it is not in function anymore.

As the Iron Gate dams represent the first impassable obstacle for migratory fish species along the Danube River from the Black Sea, a scoping mission for the preliminary assessment of the feasibility of providing free passage to migratory fish species at Iron Gates I and II was organized in May 2011 by the FAO (Comoglio 2011).

In continuation of the FAO scoping mission, the project “Towards a healthy Danube – Fish migration at Iron Gates I and II” was performed (de Bruijne 2014). Based on the fish pass design principles and on the site-specific conditions, the most adequate fish pass solutions suggested were as follows:

1. A pool-type fishway adjacent to the main HPP outflow for Iron Gate II, and
2. A mechanical or hydraulic fish lift close to the turbine outflow for Iron Gate I.

This study showed that both the technical fish passageway and a fish lift allowed for efficient movement of sturgeon. However, the dimension of fish pass, location of entrance and attraction flow has to be adequate for sturgeons. Especially, beluga requires fish pass dimensions that go far beyond the requirements of other species.

The greatest importance for fish attraction has characteristics of flow from fish passage facility – water velocity, direction, intensity of turbulence, relation to water velocity in the main stream, water temperature, presence of sediments etc. Fish attracting flow should be easily differentiated from surrounding flow by water velocity and intensity of turbulence and it should reach areas where fish concentrate or directly reach fish migration routes.

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8 SUMMARY AND CONCLUSIONS

In this study information on fish passage facilities for up- and downstream migration of sturgeons have been collected and analysed. This involves studies on fish passes that specifically had been designed for sturgeon as well as fish passes that had been designed for other species such as salmon but also enable successful passage for sturgeons.

In general, available information on sturgeon fish passes is scarce as only few fish passes for sturgeons have been built so far worldwide. Each identified case study represents a specific situation it terms of the viability of the sturgeon population of concern, dam and river characteristics and specificities of fish pass constructions. In addition, available information is often incomplete and/or inconsistent furthermore limiting comparisons among case studies. Nevertheless, for some criteria sufficient information could be collected and analysed.

In this work, data on 7 fish lifts, 13 fish locks, 9 technical fish passages, 2 nature-like bypasses, and 2 navigation locks used by sturgeon in Russia, the USA and Canada were collected as well as data about the trap and transport of sturgeon performed on 4 dams. As sturgeon mainly inhabit large rivers, analysed fish passes are located at sites with river widths ranging from several 100 m to more than 1 km (Figure 32).

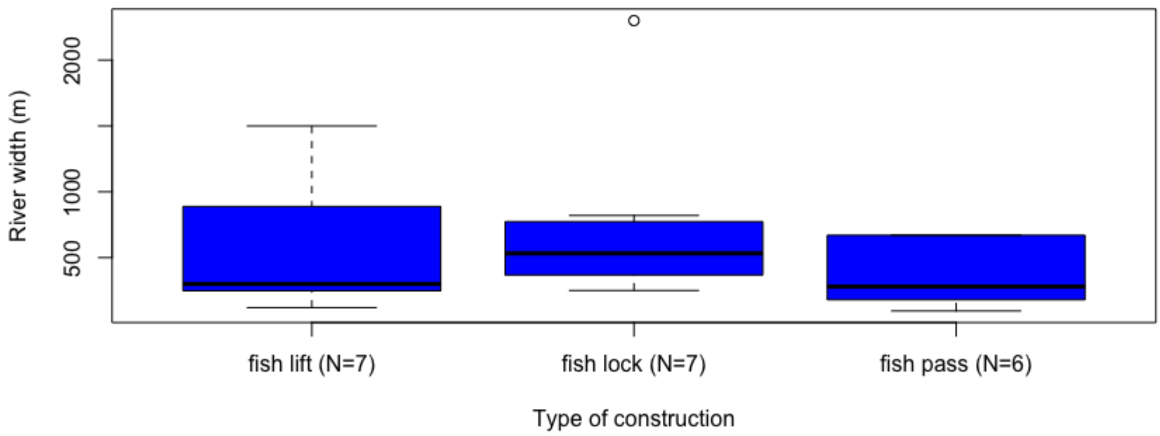

Figure 32: Comparison of fish pass type and river width

In general, analysed fish locks are limited to small dams (head <5 m). Most analysed conventional fish passes are also built at small weirs with some exceptions at large dams, while fish lifts can handle heads of >20 m (Figure 33). Fish lifts with successful sturgeon passage are located at dams with a head ranging from 7 to 23 m (median 17 m). Fish locks are limited by their design as they require sturgeon to actively swim through the lock upstream to the lock exits. Most of the conventional fish passes were also located at low heads. Only at the Columbia River a 25 m high dam pool and weir fish passes designed for salmons were

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effectively used by sturgeon for passing upstream. It seems that migratory and swimming behaviour of white sturgeons are different compared to other sturgeons although situations comparable with the Columbia River are missing elsewhere. This leads to the conclusion that there is no comparable reference of a conventional fish pass available for Danube sturgeons facing a head of 35 m at the Iron Gates.

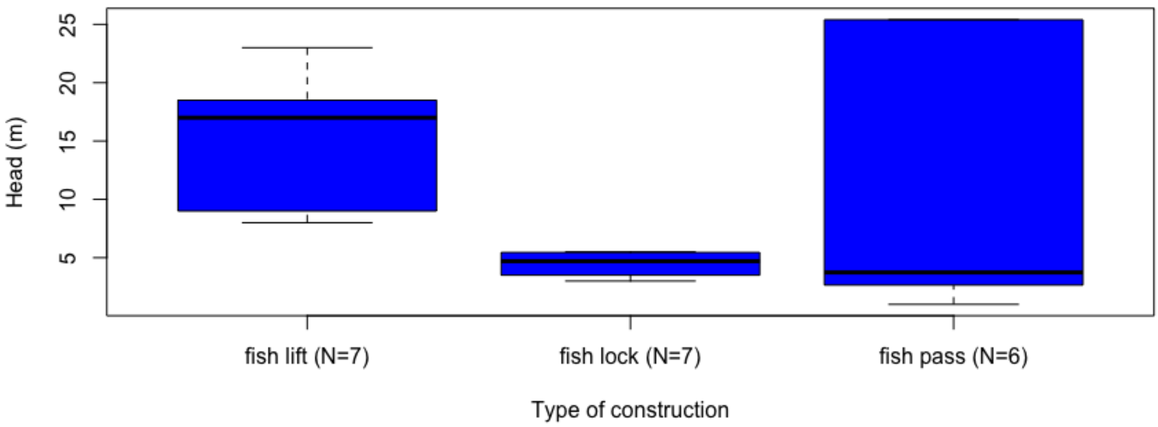

Figure 33: Comparison of fish pass type and head of dam

The passage of sturgeon over and around dams in Russia included data on beluga, Russian, stellate sturgeon, and sterlet, whereas in the USA and Canada the data originated from work with lake, shortnose, and white sturgeon. The most numerous passage of beluga sturgeon with regard to absolute numbers was recorded during 1983-1986 on the Kochetovskiy fish lock (up to 34 specimens/year) and on the Volgogradskiy fish lift from 1968 to 1973 (25-26 specimen/year). The low numbers indicate that the species is refraining from utilizing typical fish migration facilities mainly due to their dimensions but probably also due to behavioural constraints when compared to other sturgeon species. The highest number of Russian sturgeon passed via the Volgogradskiy fish lift (up to 60,000 specimens/year), and of stellate sturgeon through the Kochetovskiy and Fedorovskiy fish locks (up to 2,031 specimens/year).

When comparing total sturgeon passage data with type of fish pass facility it becomes obvious that all types are able to pass large numbers of sturgeons. Even fish lifts, always considered to be limited in quantitative fish passage due to intermitted operation can pass thousands of sturgeons if properly built (Figure 34).

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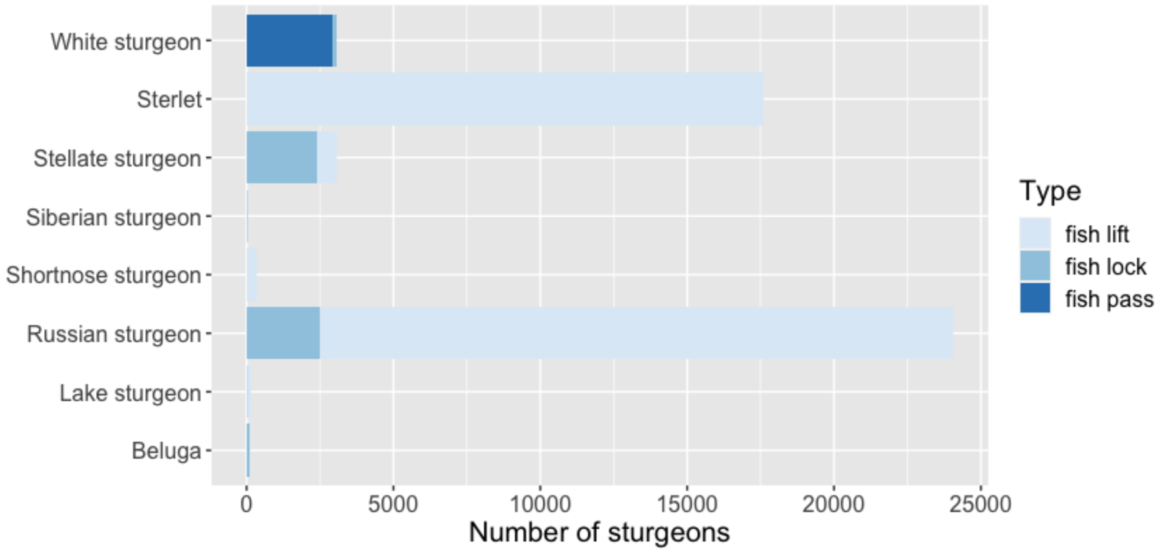

Figure 34: Total number of sturgeons passing dams in case studies analysed according to species and fish pass type

Monitoring of fish pass efficiency is very important to understand their function or malfunction. Some of the analysed case studies monitor fish passes by recording the number of sturgeons successfully passed per year or season, others include efficiency criteria based on mark recapture or telemetry studies. In order to harmonize monitoring data and to reveal an overall efficiency estimate an overall classification as indicated in Table 9 was developed and applied to the analysed case studies.

Table 9: Estimating overall fish pass efficiency based on quantitative sturgeon passage or percentage of sturgeons passed.

Efficiency based on number of sturgeons passed	Efficiency based on percentage of fish passed	Overall efficiency
1-9	1-9	low
10-99	10-49	medium
100-999	50-89	high
>=1000	90-100	very high

Figure 345 demonstrates that all types of fish passes are able to provide high passage efficiency when properly built or vice versa may fail if limitations cause low efficiency. While fish lift and conventional fish pass efficiency range from low to very high efficiency fish locks are only ranked with high and very high efficiency. Bearing in mind the low number of analysed case-study these findings should not be over-interpreted. Although being a very rough estimation

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these results show that there is evidence that fish passes for sturgeons can be efficient even if the requirements are obviously much more complex than for other species.

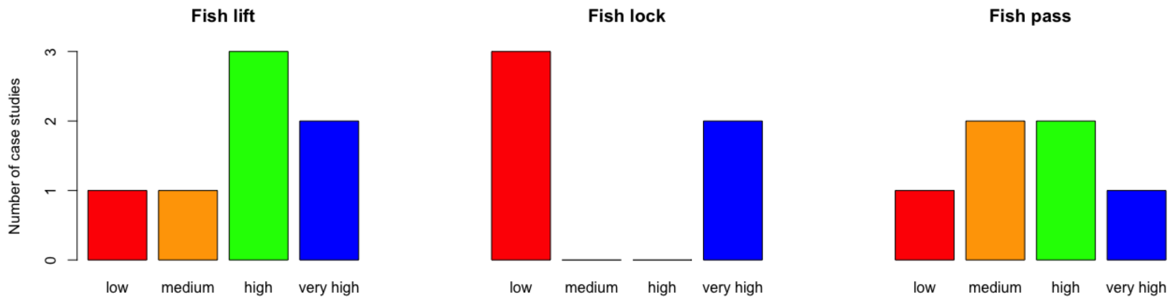

Figure 35: Range of functionality of different types of fish migration facilitation structures in comparison

Sturgeon passage efficiency for the Volgogradskiy fish lift was in the range of 10-15%, and for the Kochetovskiy fish lock in the range of 17.7-66.6%. An assessment of the efficiency of fish passage for sturgeon using telemetry was performed in 2004-2005 on Dalles fish ladders (41.2%), and after that on the St. Ours (36.4%) and Eastmain-1 passage (up to 80%), as well as on the Menominee fish lift (7.1-7.9%, **Fehler! Verweisquelle konnte nicht gefunden werden.**). Efficiency of sturgeon passage could vary due to inherent variation among species, life stages and populations, as well as due to differences in site configurations, operations and environmental conditions (Cooke et al. 2020).

Table 10: The list of analysed fishways used by sturgeons, record of sturgeon passage by navigation lock as well as trap and transport of sturgeon

Fishway , River	No[1]	Period of work	Sturgeon species[4]	Passage efficiency (%)
Fish lift				
Tsimlyanskiy, Don	1	1955-nowadays	**beluga, Russian and stellate sturgeon, sterlet**	
Krasnodarskiy, Kuban	1	1974- nowadays	**beluga, Russian and stellate sturgeon, sterlet**	
Volgogradskiy, Volga	1	1961-1988	**beluga, Russian and stellate sturgeon, sterlet**	10-15
Saratovskiy, Volga	1	1969-1988	**beluga, Russian and stellate sturgeon, sterlet**	
Holyoke tailrace, Connecticut	1	1950- nowadays	shortnose sturgeon	
Holyoke spillway, Connecticut	1	1976- nowadays	shortnose sturgeon[5]	
Menominee, Menominee	1	2015- nowadays	**lake sturgeon**	7.1-7.9
Fish lock				
Bonneville, Columbia	3	1938-1969	white sturgeon	
Kochetovskiy, Don	1	1972- nowadays	**beluga, Russian and stellate sturgeon, sterlet**	17.7-66.6
Konstantinovskiy, Don	2	1984-1988	**beluga, Russian and stellate sturgeon, sterlet**	
Nikolaevskiy, Don	2	1979-1988	**beluga, Russian and stellate sturgeon, sterlet**	
Tihkovskiy, Kuban	2	2005[2]	**beluga, Russian and stellate sturgeon, sterlet**	
Fedorovskiy, Kuban	1	1983- nowadays	**beluga, Russian and stellate sturgeon, sterlet**	
Flow divider, Volga	2	1975[2]	**beluga, Russian and stellate sturgeon, sterlet**	
Technical passage				

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Soldatov, Kuban	1	1967-1982	**beluga, Russian and stellate sturgeon, sterlet**	
Kargalinskiy, Terek	1	1956[3]	**stellate sturgeon**	
Dalles, Columbia	2	1957- nowadays	white sturgeon	41.2[6]
John Day, Columbia	2	1968- nowadays	white sturgeon	
Eureka, Fox	1	1988- nowadays	**lake sturgeon**	
St. Ours, Richelieu	1	2001- nowadays	**lake sturgeon**	36.4
Eastamin-1, Eastamin	1	2006- nowadays	**lake sturgeon**	up to 80
Nature-like bypass				
Nikolaevskiy, Don	1	1979- nowadays	**beluga, Russian and stellate sturgeon, sterlet**	
Konstantinovskiy, Don	1	1984- nowadays	**beluga, Russian and stellate sturgeon, sterlet**	
Trap and transport				
Kochetovskiy, Don		1969	**beluga, Russian and stellate sturgeon, sterlet**	
Seven sisters, Winnipeg		2009	**lake sturgeon**	
Pinopolis, Cooper		2002	**shortnose sturgeon**	
Park Mill, Menominee		2015	**lake sturgeon**	
Navigation lock				
Volgogradskiy, Volga	1	1958- nowadays	Russian and stellate sturgeon	
Pinopolis, Cooper	1	1950s- nowadays	shortnose sturgeon	

[1]number of fishway on particular dam; [2]flow divider was not in use (Kuban) or worked only 160 days in total (Volga); [3]during the first year of operation it was covered by sediment; [4]sturgeon species presented in bold letter are target species for particular fish pass; [5]shortnose sturgeon was not target species at the start of fish lift work (in 2015 modification performed to improve shortnose sturgeon passage); [6]seven of 17 white sturgeon that entered wishway passed

Fish lifts reported in this study were constructed in the period 1955-1976, with the exception of the fish lift on the Menominee dam that was constructed in 2015. The oldest fish locks, which operated from 1938 until 1969 on the Bonneville dam in the USA, were observed by a Russian fisheries scientist in 1946 and served as a prototype for fish locks in Russia. Ten fish locks were constructed in Russia with sturgeon as the target species from 1972 to 1984, and only 2 fish locks on the Tikhovskiy flow divider were built later on in 2005. Four of them are not in function as the flow dividers are not in use. Four fish locks and two fish lifts in Russia are not in function because of the decrease in sturgeon populations and their absence in tailrace as the result of illegal fishing, and the decrease in natural sturgeon reproduction due to loss of spawning habits and pollution. Passage of single sturgeons by navigation locks (shortnose sturgeon on Pinopolis dam, and Russian and stellate sturgeon on Volgogradskiy dam) was recorded but structural modifications were needed in order to provide unhindered passage.

Due to their sizes sturgeons require much larger fish pass facilities than other species. This is reflected by the dimension of the collection galleries constructed at fish lifts and fish locks for sturgeons. Due to the low proportion of flow through the fish passage facility compared to the concurrent flow (turbine or spill flow) sturgeons have to be guided by collection galleries to the entrance of the fish pass. Based on the analysed data these galleries are at the average 75 m long but may extend to 175 m. Median width is 9 m which enables unhindered manoeuvring for a multitude of sturgeon species and sizes when approaching the dam. The maximum depth of galleries depends on river depth and ranges in case studies between 7 m and 15 m with a median depth of about 12 m (Figure 36). This emphasizes the fact that sturgeons have to be

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guided from the deepest parts of the river - where they are used to migrating - to the entrances of the fish passes.

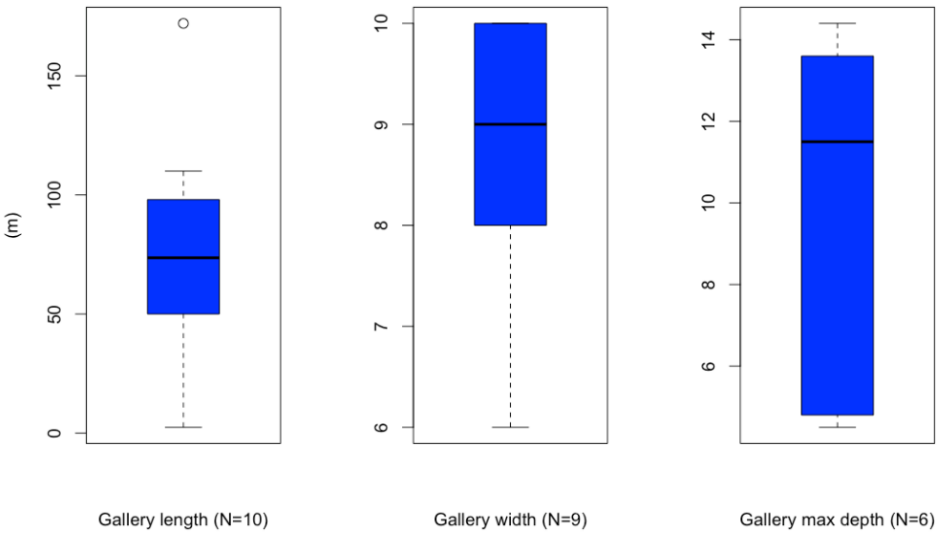

Figure 36: Dimensions of collection galleries at fish lifts and fish locks used by sturgeons

Additionally, efficient guidance depends on the appropriate provision of attraction flow. At one hand the attraction flow should not be lower than 0.5 m to be effective, at the other hand should not exceed 1.5-2.0 m to limit hydraulic stress (Figure 37).

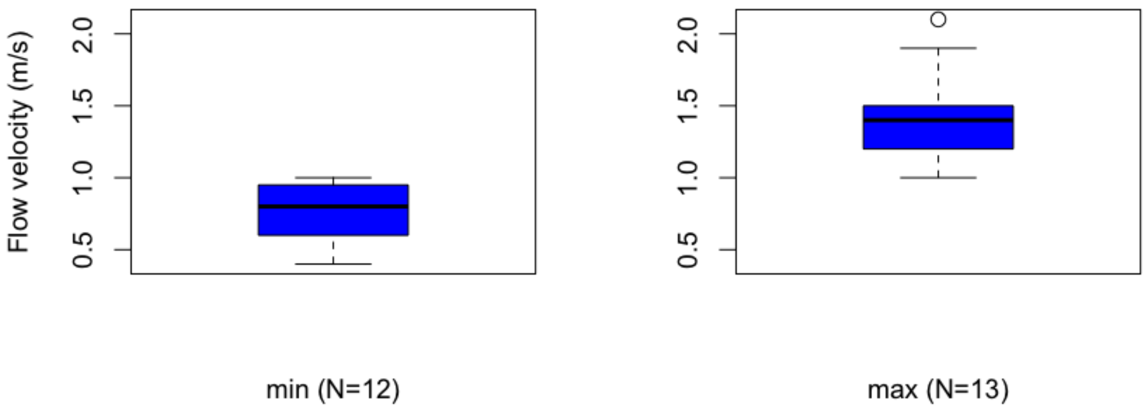

Figure 37: Minimum and maximum attraction flow at sturgeon fish pass facilities

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Conventional fish passes (pool and weir, fish ramps or nature-like bypass channels) where passage of sturgeons was observed are in general much larger than regular fish passes. The width of pools or channels mostly exceeds 10 m and may range up to 16 m (Figure 38). The length of the fish pass depends on the head of the dam but fish pass slopes are generally lower (1-1.5%) than for salmonid fish passes, with the exception of the Columbia case-study where the pool and weir fish passes are quite steep (4.7%).

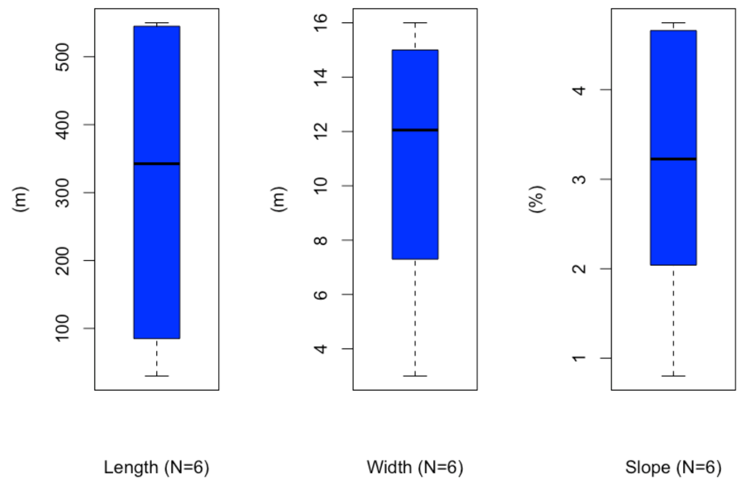

Figure 38: Length, width and slope of conventional fish passes used by sturgeons

Also the length of pools in conventional fish passes (median 5 m, maximum 9 m) reflects the need of larger dimensions for sturgeons (Figure 39). The median recorded width of slots of 0.6 m is a result of also including salmon fish passes in this analysis and might be too small for fish larger than 1.5m. A more appropriate slot target would be the one of the fish pass Geesthacht, particularly designed to handle sturgeons of up to 3m TL, with a slot width of 1.2 m.

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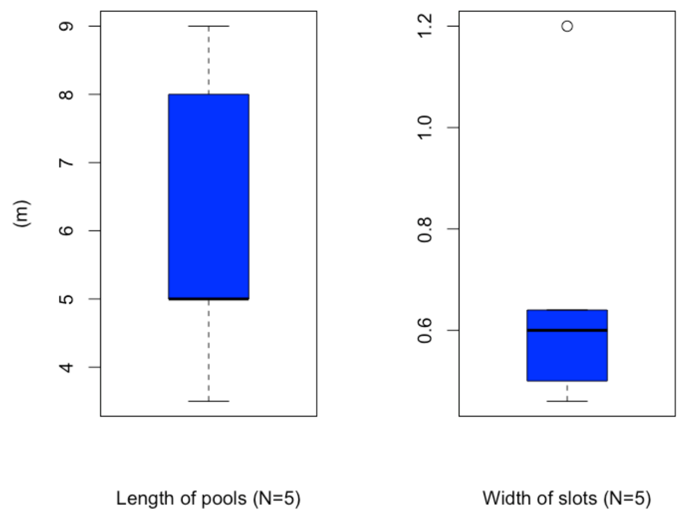

Figure 39: Length of pools and width of slots in conventional fish passes used by sturgeons

Downstream passage of sturgeon is possible through operating turbines, open spillway gates, operating ice and trash sluiceway, navigation lock or constructed bypasses. The risk of turbine strike is a function of turbine type, number of turbine blades, the clear space between them, the rotation speed and the length of the fish. This risk increases in sturgeon length but trash–rack bars prevent large sturgeon from entering turbine intakes while yearling sturgeons can pass through turbine safely with more than 90% of survival (Kynard and Horgan 2001). A passage model showed that the greatest risk is for intermediate-length sturgeons which could be solved by closer bar spacing (Jager 2006).

Downstream passage of white sturgeon by open spillway gates was recorded on Dalles dam during telemetry study (Parsley et al. 2007) but there is no data about survival rate of sturgeons which passed high spillways (Jager et al. 2016). Successful example of downstream sturgeon passage includes subadult and adult lake sturgeon downstream passage through bottom-draw sluice gates at the Slave Falls dam located on the Winnipeg River in Manitoba (McDougall et al. 2014).

Successful examples of downstream passage included also downstream bypass flumes on Menominee and Park Mill dam where angled guidance racks were constructed to guide adult and juvenile lake sturgeon as well as large canal bypass on Holyoke dam where fish are guided by louver arrays.

According to Kynard (2008), most sturgeon fishways have failed in the USA due to the unwillingness of institutions to monitor and adapt operations and infrastructure, which could also be said of sturgeon fishways in Russia. Therefore, the design of an efficient fish pass must include adaptive management and continued innovation. As passage efficiency can be modified during the work of fishways by changes in the environment (e.g., discharge, river

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morphology), a systematic and reproducible assessment of passage efficiency using telemetry will allow for their improvement and the development of new fish passage solutions (CEN 2020). Some of the performed structural and operational improvements on the mentioned fishways used by sturgeon included: adjustment of attraction flow, timing of seasonal and diurnal fish lift operation, adjustment of soak times for fish lifts, adjustment of the flow velocity in technical passage, avoidance of turbulence, improvement of the hydraulic conditions at the entrance to the fishway, and different structural improvements to avoid sturgeon damage during passage through the fishway.

Even knowledge of sturgeon passing upstream and downstream is limited, some lessons have been learned from the successes and failures of fish passes that were or are still in function in Russia, the USA and Canada (Table 11).

Table 11: Lessons learned from past experience with sturgeon

Design challenge	Examples of good and bad practice
Fishway entrance	The spillway fish lift on Holyoke dam was modified a few years ago: a new sluiceway was installed that shot the water up in an arc, passing over the entrance of the fishway into a plunge pool below. It is probably created a clear space (previously blocked by turbulence) that allowed the sturgeon to enter the lift. Since then, the numbers of shortnose sturgeon being lifted has increased dramatically (pers. comm. Theodor Castro-Santos) The tailrace fish lift on Holyoke dam is used by few sturgeon as the fish lift entrance is in the top 2m of the water column and upstream from a great upwelling of flow exiting the turbines, which creates major turbulence and no useful cues for flow direction, and further, sturgeon are near the bottom, the water is 15 m deep, so fish never are even close to the fish lift entrance (pers. comm. Boyd Kynard) A wrong decision for the position of fish locks on the dam was made on flow divider in the Volga River delta. Monitoring of sturgeon migration showed that they concentrate in the vicinity of the earth dam (Ruban et al. 2018) The interface of flow from the spillway (located on the right side of the entrance to the fishway) with that from the fishway provided satisfactory conditions for fish that swim along the boundaries of the transverse flows. These conditions changed with erosion of the riverbanks and modifications of the river bottom, resulting in a decrease in the number of fish entering the fishway on Kochetovskiy dam (Pavlov and Skorobogatov 2014) Construction of an apron in the area of entrance to fish passage made it impossible to produce an appropriate attraction flow; the interface between the river bottom and the bottom of the collection gallery was unsatisfactory (Konstantinovskiy fish lock, Pavlov and Skorobogatov 2014)
Attraction flow	Sturgeons have high threshold velocity: 0.18-0.25 m/s (Pavlov and Skorobogatov 2014) Attraction flow for Russian, stellate and beluga sturgeon is 0.7-0.9 m/s (Pavlov and Skorobogatov 2014) Water discharge from the dam could be coordinated with operation of fish-passes to ensure maximum fish attraction. In 1962 the nearest turbine to the Volgogradskiy fish lift was under repair

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	and the number of sturgeons passed was 2.5 times lower than in 1961 when two adjacent turbines worked (Pavlov 1989) The attraction flow which was close to the threshold (~0.2 m/s) was the main reason for the failure of technical passage Soldatov on the Fedorovskiy dam (Pavlov and Skorobogatov 2014)
Guidance to upstream passage	Higher attraction flows that can be detected by sturgeon traveling in the thalweg (Jager et al. 2016) To increase the attraction area, it is feasible to use “drag-up” mode when the flow velocity first exceeds the critical and then is gradually reduced. The efficiency for fish attraction increased by 50-60% when flow velocity reduced from 1.5 to 1.0 m/s on the Fedorovskiy fish lock with increase attraction for stellate sturgeon (Pavlov and Skorobogatov 2014) Electric barriers on the Krasnodarskiy dam are not more in use as fish injury and mortality was recorded Installation of electric barrier (1960-1961) didn’t guide fish effectively and induced mortality of beluga sturgeon downstream of Tsimlyanskiy dam (Boldyrev 2017)
Guidance from upstream passage	Exits locate away from the turbine intakes to avoid entrainment of sturgeon (Jager et al. 2016) Exit is not located far away from the turbine intakes and water velocity (0.1 -0.15 m/s) was lower than sturgeon threshold velocity (0.18-0.25 m/s) on Kochetovskiy fish lock and was not in possibility to provide fish release at safety distance from dam (Pavlov and Skorobogatov 2014)
Guidance to downstream passage	Full-depth guidance structures that extend seamlessly to the river bottom (Jager et al. 2016) The use of a guidance bar rack leading to a bypass chute on the dam to successfully protect downstream migrant sturgeons at Holyoke dam (pers. comm. Boyd Kynard)
Natural bypass	Rock or nature-like fishways with wide pools that do not require jumping (Bruch 2008) The eggs of stellate sturgeons were collected in the nature-like bypass channel on the Konstantonovskiy dam (Pavlov and Skorobogatov 2014)
Fish ladders	Wide ladders with large and submerged orifices (Parsley et al. 2007) The monitoring of fish in 2007 showed that flow velocities of 2 m/s were too high; remedial work carried out in 2008 allowed for the reduction of flow velocities to 1 and 1.4 m/s (Eastamin-1 ladder, D’Amours et al. 2019) The turning basin impeded progress of lake sturgeon ascent in the fishway (Thiem et al. 2016)
Lifts and locks	Records taken between 1938 and 1969 show that 97% of sturgeon passing the dam preferentially used the locks rather than the ladders, even though the locks operated for only 12 of 31 years that were monitored (Bonneville fish locks, Wittmann-Todd et al. 2003) Filling lifts slowly to minimize turbulence (Cooke et al. 2002) The problem arising from considerable differences in water velocities and turbulence along the collection gallery (Krasnodarskiy fish lift, Pavlv and Skorobogatov 2014)

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	Encouraging sturgeon to exit by use a pulse of flow and/or leave the upper gate open (Cooke et al. 2002) Timing seasonal and diurnal lift operation to match sturgeon migration (Kynard 1998) Elevator captures of lake sturgeon increased with higher water attraction, longer soak times, nocturnal operation and water temperature near 12.7°C (Menominee fish lift, Raabe 2019)
Use of ship lock for fish passage	Navigation lock could be seen as an option for sturgeon passage but structural modifications are needed (Cooke et al. 2002) Individual specimens of Russian and stellate sturgeon were recorded to pass the Volgogradskiy dam by ship lock, but the passing of beluga sturgeon was not recorded (Shashulovskiy and Ermolin 2005)
Downstream passage	Providing deep spill gates that are more easily found by benthic fish (Parsley et al. 2007)
Translocation	The lake sturgeon is suitable for trap-and-transport as it is easy to catch, has a low mortality when fishing by gill nets, and exhibits rapid recovery from netting and handling stress (McDougall et al. 2011) The transporting of captured lake sturgeon above the dam via a tank trailer towed by a truck. Telemetry studies have shown that nearly 100% of transported fish moved back through the dams within 1-2 years (pers. comm. Robert Elliot) Trap-and-transport of sturgeon was organized from 1952 till 1962 from Lower Don River and from the Volga River to Tsimlyanskiy reservoir. Sturgeon mortality recorded during transport and in reservoir (Boldyrev 2017) Trap-and-transport by barge and transport vessel on Kochetovckiy dam - Experiments revealed that when the angle of the ramp between the river bottom and barge was 16°, only shad, sichel and bream entered the barge while stellate sturgeon, Russian sturgeon, sterlet, pike-perch and vimba bream did not enter because of the whirlpool area on the ramp; this angle could be no larger than 6-8° to avoid turbulence (Pavlov and Skorobogatov 2014)
Natural and artificial spawning grounds	Successful spawning of lake sturgeon on two artificial spawning grounds (D'Amours et al. 2019) The building of the Tsimlyanskiy dam on the Don River in 1953 cut off half of available spawning habitats for stellate sturgeon and mainly all for beluga and Russian sturgeon (Boldyrev 2017)

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9 KEY MESSAGES

1. Although information on sturgeon passage across dams is still very scarce, examples documented in this report show that fish pass facilities are in general able to provide upstream passage for sturgeon species.
2. In principle, different types of fish pass facilities, i.e., fish lifts, fish locks and conventional fish passes, are able to provide upstream passage for sturgeon species.
3. In general, analysed fish locks are limited to small dams (head <5 m). Most analysed fish passes are also built at small weirs with some exceptions at large dams, while fish lifts can handle heads of >20 m.
4. Regardless of the type of fish pass sturgeons use successfully, dimensions of facilities are much larger than those of other species.
5. Efficiency varies considerably among case studies analysed and depends on a number of factors. Detailed case-specific knowledge on migratory behaviour at dam sites as well as current and bottom topography are required to design functioning fish pass facilities.
6. As sturgeons mainly inhabit large rivers collection galleries are essential to guide fish to fish pass entrances. Entrances should be located at the parts of the river where sturgeon are expected to migrate and aggregate below the dam.
7. There is consistent information that attraction flow velocity should be with the range of 0.8-1.4 m/s. Considering the dimensions of sturgeon fish pass facilities requirements for attraction and/or auxiliary flows go far beyond conventional fish passes.
8. Analysed examples demonstrate that many sturgeon fish passes have been redesigned and/or adapted over time to increase efficiency. Therefore, options for adjusting key elements such as auxiliary flow, and improve flow patterns in the fish passage facilities should be implemented beforehand to enable adjustments during first years of operations. For construction elements that cannot be redesigned (slope, dimensions) it is recommended to plan for larger dimensions of the facility than for smaller. The case of beluga utilizing fish migration structures so that the fish avoid facilities that are too narrow/shallow and impair their navigation.
9. For downstream migration, available information is limited and intensive research on this topic is necessary to fill this large knowledge gap as soon as possible. In few cases full-depth guidance structures leading to bypass channels on the dam have proven to be successful in protecting downstream migrant sturgeons.

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