Restoration and ecology of sterlets in the Austrian Danube – The way from LIFE-Sterlet to LIFE Boat 4 Sturgeon

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Abstract

Sturgeons are an essential faunal element of the Danube and provided a link between the Alpine Danube basin and the Black Sea through their migration in the past. Today, two out of six Danube sturgeons are already regionally extinct, and the remaining species are threatened with extinction due to poaching, bycatch, migration barriers and habitat loss. A variety of projects are pushing conservation and reintroduction efforts. However, those projects only have a chance of success in a coordinated manner and within international cooperation. The aim of the LIFE-Sterlet project was to strengthen the population of the highly endangered sterlet (*Acipenser ruthenus*) in the Upper Danube and to increase the knowledge about habitat use, migration and autecology. The follow-up project LIFE Boat 4 Sturgeon builds upon the methods and results of the LIFE-Sterlet project and has the aim to create a genetically diverse captive broodstock of mature animals of the last four Danube sturgeon species.

Introduction

For more than 200 million years, sturgeons have inhabited the aquatic ecosystems of the northern hemisphere. However, populations have reached an all-time low and sturgeons are considered the world's most endangered animal group (IUCN 2022). In addition to their characteristic physique and sizes of over five meters, sturgeons are characterized by their longevity, they can live over a hundred years and, depending on the species, a very late sexual maturity from 5 to 22 years with reproductive intervals from up to 6 years. As long-distance migrants, they require different habitats in order to complete their life cycle. Most of the species are anadromous fish that live in the sea and migrate upstream into rivers for spawning. In the past, enormous distances were covered for example more than 2000 km from the Black Sea into the Bavarian Danube (Bemis et al. 1997; Billiard & Lecointre 2001). For the potamodromous sterlet (*Acipenser ruthenus*), migration distances up to 300 km were documented (Holčík 1989).

Due to their life cycle and longevity, sturgeons are indicators for long-term functioning and sustainably used river ecosystems and are therefore so-called flagship and umbrella species. Two of the main reasons for their decline are blocked migration routes by dams and a loss of access to spawning habitats. Since the construction of the hydropower plants (HPP) at the Iron Gate between Serbia and Romania, only the lowest 900 km of the Danube are freely accessible and a massive decline as well as extinction of the anadromous species in the upper parts of the Danube were observed (Bemis & Kynard 1997; Hensel & Holčík 1997; Lenhardt et al. 2006; Sandu et al. 2013). Potamodromous species are not dependent on migrations between salt- and freshwater. However, due to river fragmentation, subpopulations are no longer in contact resulting in a depletion of the gene pool (Ludwig et al. 2009). Currently available fish passes along the Upper Danube are unsuitable for sturgeons, based on monitoring results and the sturgeon's ecology.

In addition to the destruction of important habitats and migration routes, overfishing further threatens sturgeon populations. In earlier centuries, overexploitation in the Upper and Middle Danube led to grave decline of larger sturgeon species. A long life cycle, late sexual maturity and perennial reproduction cycles make sturgeons particularly vulnerable to overfishing and stocks take a long time to recover. Nowadays, fishing bans in all countries along the Lower Danube and in the Black Sea exist for all native species and trading with wild sturgeon products is prohibited. However, poaching and by-catch still contribute illegally to overexploitation. Main drivers are the high economic value of caviar, continued popularity of sturgeon meat in countries bordering the Black Sea and the difficult socio-economic situation.

As a result of river regulations, the availability and habitat diversity dramatically decreased causing bottlenecks for some stages in the life cycle (Friedrich et al. 2018). Additional stressors are water pollution (Lenhardt et al. 2006) and hybridization with escaped or illegally stocked allochthonous sturgeon species from aquaculture (Ludwig et al. 2009). Of the six Danube sturgeon species, the European sturgeon (*Acipenser sturio*) is already extinct in the catchment area of the Black Sea. Due to the lack of evidence through traditional surveys, eDNA studies or documented by-catch, the ship sturgeon (*Acipenser nudiventris*) is considered as functionally extinct. The remaining three anadromous species, namely the Beluga sturgeon (*Huso huso*), stellate sturgeon (*A. stellatus*) and Russian sturgeon (*A. gueldenstaedtii*), are threatened with extinction and restricted to the Lower Danube below the first dam of the Iron Gates. For Beluga sturgeon and stellate sturgeon low reproduction rates are documented, whereas last reproductions of Russian sturgeons were recorded in 2007 and 2011 and recently in 2022 (Paraschiv pers. comm.). The sterlet is a freshwater species and was formerly widely distributed along the Danube. Over the last decades populations were

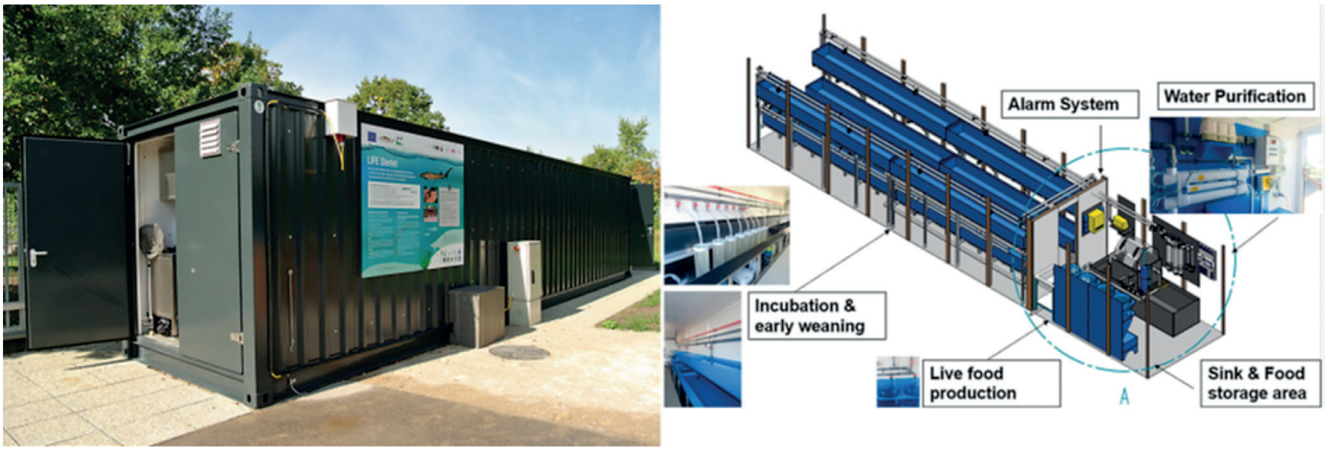

Figure 1. The hatchery container: left - outside view; right - technical sketch

declining, especially in the Upper and Middle Danube. In the Upper Danube only one self-sustaining population in the area of Jochenstein is known (Friedrich et al. 2014, 2018). In the Austrian Danube, the sterlet is classified as "critically endangered" by the Austrian Red List (Wolfram and Mikschi, 2007).

Against this background, the LIFE-Sterlet project (2015-2022) aimed to strengthen the remnant sterlet population in Austria by reintroducing juvenile sterlets, to study the migration behaviour and to gain knowledge on the autecology and population size of the sterlet in the Austrian Danube.

Methods

Hatchery

A prerequisite for the successful reintroduction of highly endangered fish species or fish species that have become extinct in the wild is the use of locally adapted, genetically autochthonous strains which should also exhibit a high level of genetic diversity. In addition, young fish have to be imprinted to the water body to initiate "homing" behaviour. The rearing methods should focus on fitness and adaptation in the wild. From 2017 to 2022, eggs from mother fish in the Hungarian Danube were used. During monitoring surveys, a residual population of old sterlets below Vienna was detected. From 2018 to 2022, wild fish from this population could be independently propagated. The incubation of the eggs and rearing of the fish took place in a rearing container on the Viennese Danube Island (*fig. 1*) using Danube water. The water was not treated biologically, chemically or thermally in order to simulate conditions in the wild as closely as possible. The young sterlets (*fig. 2*) were first fed with live nauplii of brine shrimps (*Artemia sp.*) and later with chopped up or whole midge larvae (Chironomidae, Culicoidea) and shrimp (*Mysis sp.*). The release of juveniles into the project areas Wachau, Nationalpark Donau-Auen and Morava-Thaya system took place at irregular intervals from the feeding postlarval stage in mid-May until September when juveniles have already reached total lengths of 25 to 35 cm. The stocking of especially younger stages was done by boat, far from the shore in order to avoid direct exposure to the feeding pressure of invasive Gobiidae in rip-rap areas or wave impact by shipping. Some of the juveniles were marked with PIT tags in order to be able to allocate recaptures.

Habitat and migration monitoring

An acoustic telemetry study was implemented to collect information on habitat use and migration patterns of wild and stocked sterlets. A total of 38 sterlets were tagged with hydroacoustic transmitters, released in the Nationalpark Donau-Auen and observed between 2020 and 2021 for 1.5 years. Five of the sterlets were wild fish that were caught via netfishing below the HPP Freudenau. The stocked sterlets were reared under semi-natural conditions in the course of the LIFE Sterlet project and hatched in the years 2016, 2017 and 2018. The study area was located between the two HPPs Freudenau (AUT) and Gabčíkovo (SVK) with a free-flowing section of roughly 45 km and 40 km of impoundment. Along this section, 14 hydrophones were distributed and fixed on navigation buoys. In addition to the continuously collected data from the stationary hydrophones, mobile tracking was carried out monthly. Additionally, a study on small scale habitat use of sterlet was conducted. During spawning season from March to May 2021, an area of 17.000 m^2 was observed over 43 days using an array of five hydrophones

Figure 2. Juvenile sterlets

below the HPP Freudenau (*fig. 3*). The study focused on five sterlets which were caught in the study area.

Population monitoring

A population monitoring in the section east of Vienna was carried out from 2018 to 2021 via netfishing in the tailwater of the HPP Freudenau (Neuburg & Friedrich in prep.) Trammel nets with inner and outer mesh sizes of 100 and 40 mm were set overnight in deep areas below the weir fields, fixed to the bottom with anchors and marked with buoys on the surface. Captured sterlets were examined for PIT tags and marked if none was present. After length and weight was measured and genetic samples were taken, the fish were returned to the Danube. During spawning season, suitable sterlets were temporarily transferred to the rearing container on the Danube Island for the purpose of artificial reproduction. The population size was determined with the mark-recapture method. Due to the marking with PIT tags, each sterlet can be identified, creating an individual record history for each fish. The recaptures serve as a basis for calculating the population size (Pollock 1980). The population size for the sampled area was calculated with a model for an open (POPAN; cf. Schwarz et al. 1993) as well as for a closed population (Mt, capture probability varies with time; cf. Otis et al. 1978). Because the sterlet is a migratory species (Holcik 1989), migration processes in and out of the sampling area cannot be excluded. Therefore, it can be assumed that an open population model is more suitable. However, sterlets can reach a relatively old age of approx. 25 years and the study took place over a period of four years, which means that mortality events can be neglected. Current data of the observed population suggests that recruitment processes do not play a role (Friedrich et al. 2014). In case of random migrations in and out of the sampled area (cf. Ratschan et al. 2017), migration processes can also be neglected (Kendall 1999). Therefore, the results of a closed model can be considered as plausible as well. In addition, the population size of the sterlets below Freudenau and the population size of the sterlets in the area of Jochenstein were calculated based on their genetic diversity. A total of 132 samples from Jochenstein and 37 samples from the area of the National Park from

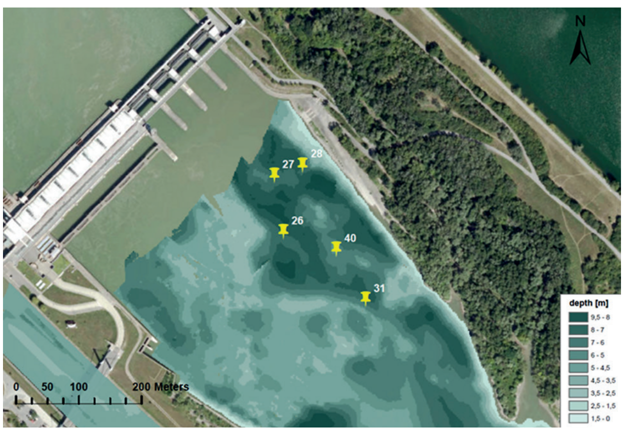

Figure 3. *Hydrophone positions of the 2D- telemetry study*

sterlets caught between 2014 and 2021 were genetically analysed. Additionally, 340 samples from previous studies from other Danube sections were used. Fish with signs of hybridization and partial Volga genotypes from uncontrolled stocking were excluded from the calculation. Two models for panmictic (random mating) and assortative mating (non-random mating) (Jones & Wang 2010) were calculated.

Results

Hatchery

Between 2017 and 2022 more than 238 000 juvenile fish were reared and released in the project areas. The hatching and rearing in Danube water differs due to temperature fluctuations, increasing turbidity during floods, etc. (Friedrich & Eichhorn in prep.) from commercial rearing under controlled conditions (cf. Chebanov et al. 2011). However, mortality rate at the various life stages was within the range of empirical values of commercial farms.

Habitat and migration monitoring.

Through the telemetry study, five different migration patterns could be distinguished. Wild sterlets showed the smallest migration ranges and were mainly detected below the HPP Freudenau together with a few stocked sterlets. Most of the stocked fish migrated immediately downstream after their release, whereas some migrated upstream again. Observed migrations could not be related to changes in temperature and discharge. The variety of migration patterns was interpreted as the individual ability to adapt to a new environment and explorative behaviour. Observed maximum and average migration distances of 100.7 km and 37.7 km (SD ± 27.7 km) and observed aggregations of sterlets below migration barriers, like the HPPs Freudenau and Gabčíkovo, highlight the need to restore longitudinal connectivity in the Upper Danube. The array in the tailwater of the HPP Freudenau showed that all fish used core areas between 3 732 m^2 and 4 739 m^2 and that the used habitat of individuals overlapped to some extent. The maximum number of encounters between two individuals was 331, increasing with water temperature (> 9 °C). On average, sterlets preferred depths of 9.7 m (SD ± 1.8 m), with no significant difference between day and night. The observed movement distance of individual fish within the array ranged from 786 m (SD ± 596 m) to 1 670 m (SD ± 788 m) per day.

Population monitoring

During 41 netfishing sessions, a total of 68 captures of 38 individual sterlets were made. Some fish were captured several times – up to five times – during the four-year study. The number of recaptures increased from no recaptures in 2018 to 16 recaptures in 2021. Figure 4 shows that the majority of all captured sterlets were females (n = 27, 71.1%), whereas only a small proportion could be identified as males (n = 7, 18.4%). The sex of four fish could not be clearly identified (10.5%). All individuals were adults. Table 1 shows the lengths and weights of the captured fish. Two sterlets had to be excluded from further analysis due to missing weight measurements. With a length of 800 ±

Release site	Larvae	3-5 cm	5-10 cm	10-15 cm	15-20 cm	20-30 cm	>30 cm	TOTAL
Wachau	17 500	28 700	4 650	1 869	910	1 369	821	55 819
Greifenstein-Freudenau	23 500	8 800	1220	880	382	1 218	234	36 234
Nationalpark Donau-Auen	34 000	51 700	10 827	1 918	1 908	2 948	1 048	104 349
Morava CZ	8 500	5 500	7 610	4 593	670	1 962	569	29 404
Morava AT	8 000	2 800	1 050	-	50	124	131	12 155
Marchfeldkanal	-	-	-	-	-	200	-	200
Asten	-	-	-	-	-	200	-	200
Traisen	-	-	-	-	-	253	50	303
Total	**91 500**	**97 500**	**25 357**	**9 260**	**3 920**	**8 274**	**2 853**	**238 664**

Table 1. Number of released juvenile sterlets from 2017 to 2021

62 mm and a mean weight of 3 294 ± 1 324 g, females were evidently larger and heavier than males (660 ± 73 mm, 1 350 ± 358 g). Mean length and weight of unidentified fish were 800 ± 114 mm and 2 850 ± 1 196 g.

The results of both population models were quite similar and overlapped to some extent. The population size of sterlets in the sampled area, estimated with the open population model, resulted in 53 individuals (95% confidence interval (CI) = 43-80) whilst the model for closed populations estimated 48 individuals (95% CI = 42-63) (Neuburg und Friedrich 2022). The population genetics for the sterlets downstream of Vienna resulted in 75 reproductive individuals (95%, CI = 46-146) based on a panmictic population and 57 individuals (95% CI= 34-110) based on an assortative population (Friedrich and Ludwig in prep.). Analyses from the population of Jochenstein showed a size of 99 reproductive individuals (95% CI= 74-136) in a panmictic population and 60 individuals in an assortative population (95% CI= 41 -85) (Friedrich & Ludwig in prep.).

Discussion

Due to the late sexual maturity of the sterlet (4 to 5 years for males, 5 to 6 years for females) and the challenges of sampling in the Danube, the long-term success of implemented measures during the LIFE-sterlet project must be evaluated in detail after the project period. The rearing method in Danube water and the use of live food has proven to be promising. Moreover, successful rearing trials with other fish species as well as the mobility of the container imply a versatile use of the rearing system. The rearing and monitoring led to an important gain in knowledge concerning the autecology of the sterlet with regard to behaviour, sexual maturity, spawning season and migration patterns. The size limit for angling sterlets in some federal states in Austria of 40 to 50 cm is definitely too small, since sexual maturity is reached with 55 to 60 cm in males and 60 to 70 cm in females. The phototactic behaviour in the larval and post-larval phase as well as the results of the telemetry studies illustrate once again the relevance of upstream and downstream passage for sterlets and the availability of near-natural, river-typical habitats.

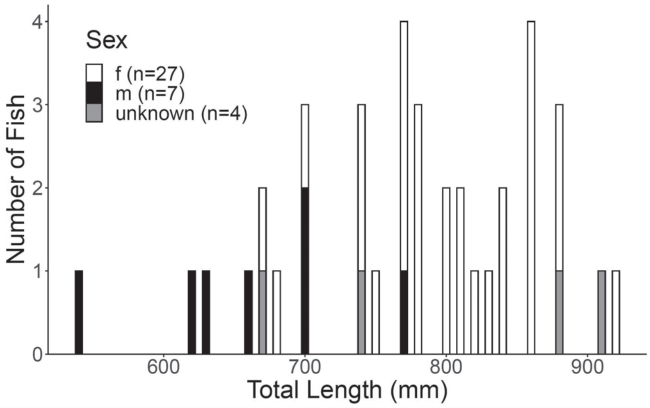

Figure 4. Length-frequency-diagram of caught sterlets

LIFE Boat 4 Sturgeon

The follow-up project LIFE Boat 4 Sturgeon builds upon the methods and results of the LIFE-Sterlet project. In the long term, the monitoring is to be continued and intensified to document the development of the population. Furthermore, an investigation along the whole Danube for possible residual populations, will be carried out. For all four remaining Danube sturgeon species, a genetically diverse captive broodstock of mature animals will be established in at least two locations (AT and HU). Those stocks will be maintained over the long-term to preserve the gene pool and to support the three anadromous species in the Lower Danube with genetically diverse, autochthonous and fit juveniles. In Austria, a floating rearing station in the Danube in the centre of Vienna will be built in addition to the existing LIFE-Sterlet hatchery container. Further reintroduction measures in the Upper Danube are based on the surveys along the Austrian Danube. Within the LIFE-Sterlet project, a total of 12 sterlet families could be established and a part of each family was kept as future broodstock. The mother fish stock of all species will be constantly expanded through different genotypes and the reproduction through a studbook enables the greatest possible genetic diversity of the offspring. The time horizon for the measurements extends over several years to decades due to the critical population sizes, existing negative influences and late sexual maturity, especially for the anadromous species. In parallel, the restoration of the habitats especially of the longitudinal continuum not only at the Iron Gates but also at upstream migration obstacles is indispensable.

References

Bemis WE, Kynard B (1997): Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Environmental Biology of Fishes, 48, 167–183. https://doi.org/10.1023/A:1007312524792

Bemis WE, Findeis EK, Grande L (1997): Part 1: Diversity and evolution of sturgeons and paddlefishes – An overview of Acipenseriformes. Environmental Biology of Fishes, 48, 25–71. papers3://publication/uuid/53114CA8-331D4F99-B921-642E4F972389

Billard R, Lecointre G (2001): Biology and conservation of sturgeon and paddlefish. Reviews in Fish Biology and Fisheries, 10, 355–392. https://doi.org/10.1023/A:1012231526151

Chebanov M, Rosenthal H, Gessner J, Van Anrooy R, Doukakis P, Pourkazemi M, Williot P (2011): Sturgeon hatchery practices and management for release. Guidelines FAO Fisheries and Aquaculture Technical Paper No. 570, Ankara, 110 pp.

Friedrich T, Eichhorn H (in prep): Durations of incubation & larval development of sterlets (A. ruthenus) in river water rearing under semi-natural conditions

Friedrich T, Ludwig A (in prep): Genetic population assessment of two sterlet populations in the Upper Danube, Austria.

Friedrich T, Schmall B, Ratschan C, Zauner G (2014): Die Störarten der Donau: Teil 3: Sterlet, „Stierl“ (Acipenser ruthenus) und aktuelle Schutzprojekte im Donauraum. Österreichs Fischerei, 67, 167–183.

Friedrich T, Gessner J, Reinartz R, Striebel-Greiter B (2018): Pan-European Action Plan for Sturgeons. Strasbourg, 85 pp.
https://rm.coe.int/pan-european-action-plan-for-sturgeons/16808e84f3

Hensel K, Holĉík J (1997): Past and Current Status of Sturgeons in the Upper and Middle Danube River. Environmental Biology of Fishes, 48,185–200. https://doi.org/10.1007/0-306-46854-9_9

Holĉík J (1989): Acipenser ruthenus (Linnaeus, 1758). In: Holĉík J (Ed.): The Freshwater Fishes of Europe. Vol.1. Part II. General Introduction to Fishes – Acipenseriformes. AULA, Wiesbaden, 469pp.

IUCN (2022): https://www.iucn.org/press-release/202207/migratory-monarch-butterfly-nowendangered-iucn-red-list. Accessed: 08.08.2022

Jones O, Wang J (2010): COLONY: a program for parentage and sibship inference from multilocus genotype data. Molecular Ecology Resources, 10, 551–555.

Kendall WL (1999): Robustness of closed capture-recapture methods to violations of the closure assumption. Ecology, 80(8), 2517–2525.

Lenhardt M, Jarić I, Kalauzi A, Cvijanović G (2006): Assessment of extinction risk and reasons for dec-line in sturgeon. Biodiversity and Conservation, 15, 1967–1976. https://doi.org/10.1007/s10531-005-4317-0

Ludwig A, Lippold S, Debus L, Reinartz R (2009): First evidence of hybridization between endangered sterlets (Acipenser ruthenus) and exotic Siberian sturgeons (Acipenser baerii) in the Danube River. Biological Invasions, 11, 753–760. https://doi.org/10.1007/s10530-008-9289-z

Neuburg J, Friedrich T (in prep): First description of a remnant sterlet (Acipenser ruthenus Linnaeus, 1758) population in the eastern Austrian Danube.

Otis DL, Burnham KP, White GC, Anderson DR (1978): Statistical Inference from Capture Data on Closed Animal Populations. Wildlife Monographs, 62, 3–135.

Pollock KH (1980): Capture-Recapture Models: A Review of Current Methods, Assumptions and Experimental Design. Department of Statistics, North Carolina State University, 32pp.

Ratschan C, Zauner G, Jung M (2017): Der Sterlet im oberen Donautal – Identifikation der Laichhabitate mittels Telemetrie, Endbericht 2016. Ezb – TB Zauner GmbH, Technisches Büro Für Gewässerökologie Und Fischereiwirtschaft, 67.

Sandu C, Reinartz R, Bloesch J (2013): Sturgeon 2020—A program for the protection and rehabilitation of Danube sturgeons. Danube Sturgeon Task Force (DSTF) & EU Strategy for the Danube River (EUSDR) Priority Area (PA) 6—Biodiversity, 24pp.

Schwarz CJ, Bailey RE, Irvine JR, Dalziel FC (1993): Estimating salmon spawning escapement using capture-recapture methods. Canadian Journal of Fisheries and Aquatic Sciences, 50, 1181–1197. https://doi.org/10.1139/f93-135

Wolfram G, Mikschi E (2007). Rote Liste der Fische (Pisces) Österreichs. Rote Liste gefährdeter Tiere Österreichs, Teil 2. Grüne Reihe des BM für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft 138.

Further literature

Friedrich T (2018): Danube Sturgeons: Past and Future. In Schmutz S, Sendzimir J (Eds): Riverine Ecosystem Management, Aquatic Ecology Series 8, 507- 518. https://doi.org/10.1007/978-3-319-73250-3_26507

Development perspectives and management options for the ecology of the urban floodplain Lower Lobau

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Abstract

The Lower Lobau is an urban floodplain system, which was disconnected from the main channel of the Danube in the 1880s. In its present state, the area is dominated by groundwater-fed and back-flooded successional floodplain water bodies hosting a high biodiversity. The main threat for the system is that strong terrestrialization processes are prevailing, significantly accelerated by ongoing hydrologic alterations. To stop the ongoing loss of aquatic habitats and their associated community, different management concepts for a step-wise rehabilitation have been developed. In this article, we give an overview of the prognosis of these different management options and development perspectives for the system.

Introduction

Terrestrialization, or hydrarch succession, is a plant succession that starts in shallow water bodies and culminates in a forest. In natural floodplain water bodies, it is countered by rejuvenation due to dynamic geomorphic processes (scouring floods, channel migration; Ward et al. 2001). In regulated rivers, terrestrialization often remains the only ongoing geomorphic process and therefore floodplain management and restoration aim to reverse this trend of decreasing waterbody area (Schiemer et al. 1999). Successional communities are complex and diverse commu-