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Can Anadromous Sturgeon Populations be Restored in the Middle Danube River?

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Abstract: All anadromous sturgeon species are critically endangered in the Danube River. Action plans and conservation programs have been worked out since 2000 with the aim to draw attention to the critical situation of sturgeon populations and convey to the public and policy makers the urgency of some remedial measures. This paper reviews the major threats to anadromous sturgeons in the Middle Danube River, *i.e.* historical over-exploitation of populations, loss of spawning habitats, interruption of migratory routes between the key habitats, and pollution. The suggested in-situ conservation measures are critically evaluated with regard to the efficiency of fish pass facilities at hydropower dams, the estimation of survival rates of sturgeon populations, and the assessment of stock-recruitment from artificial propagation.

Keywords: Overfishing, river fragmentation, Iron Gate dam, spawning migration, homing, stocking

Introduction

Anadromous sturgeons, *i.e.* beluga sturgeon (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedti*) and stellate sturgeon (*A. stellatus*) used to migrate upstream to spawn in the Middle Danube River, and then return to the Black Sea for spending most of their lifetime (Hensel, Holčik 1997). They require a wide range of habitats over large river stretches, and migration is an integral element of their life cycle. Therefore, they are particularly sensitive to impacts of fishery and interruption of longitudinal connectivity in river systems. Since 2000, several conservation plans (Bloesch *et al.* 2006, Reinartz 2002, Sandu *et al.* 2013) have been worked out with the aim to raise awareness of the critical situation of the Danube sturgeons and prevent their extinction. Conservation of sturgeon populations is a highlighted effort in the EU Strategy for the Danube Region and the urgent remedial measures and requirements are described to the public and policy makers in the program "Sturgeon 2020" (Sandu *et al.* 2013). Recovery of the over-exploited sturgeon populations in the fragmented and altered river systems in the Danube River Basin is a complex issue and a difficult problem to solve. This paper presents some data and provides proposals concerning fish pass efficiency on hydropower dams, as well as estimation of effective stocking intensity for sturgeons.

Threats to anadromous sturgeon stocks in the Middle Danube River

Human induced environmental degradation and intense fishery led to a long-term downtrend of sturgeon populations and the extinction of all anadromous species in the Middle Danube River. Major threats for Danube River sturgeons are the over-exploitation of populations, the loss of reproduction habitats, and the interruption of migratory routes between key habitats of their life cycle. Additionally, populations can be impacted by toxic pollutants accumulated in the river sediments and in biota through the food-chain, which causes chronic sub-lethal effects, such as a decline in reproduction capacity or change of behaviour (Jarić *et al.* 2011, Zahedi *et al.* 2013).

Anadromous sturgeons were one of the most important target species of the historical Danube River fishery because their meat and caviar were valuable commodities. Sturgeons are highly vulnerable to impacts of fishery due to their specific behaviour and life history. Intense overfishing of populations resulted in a significant decline of catches in the upper and middle zones of their distribution area in the Post-Medieval times.

The decline of sturgeon populations in the Middle Danube River occurred earlier than in the Lower Danube River since former meta-populations of each anadromous species consisted of several sub-populations using spatially separated spawning grounds along the Danube River. The long- and short-migratory sub-populations had natal homing ability to return to their original spawning sites (Stabile *et al.* 1996, Dugo *et al.* 2004). The individuals of the long-migratory (Middle Danubian) races migrated upstream of the Black Sea to more distant (> 1000 km) spawning sites. Fishery mortality rate (referring to individuals which are removed from the stock by fishing) proportionally related to the extent of the spawning runs in the rivers, and survival of migrants spawning in the Middle Danube River could be several times lower than survival of individuals in the Lower Danubian short-migratory sub-populations. The intensity of post-medieval sturgeon fishery in the Middle Danube River can be estimated on the basis of a map of Marsigli, which indicates six sturgeon fishing sites along a 70 km long stretch of the Danube downstream of Budapest at the end of the 17th century (Fig. 1). Some historical descriptions illustrate the high fishing pressure. For instance, in November of 1553, 77 specimens of beluga sturgeon were caught within a day at the fishing site of Aszód-puszta in the Little Danube side arm upstream of the tributary of the Váh River (Unger 1931), and the reported annual catch was 27 tons in a 45 km long section of the Danube River between Paks and Szeremle (rkm 1530-1475) in 1746 (Solymos 1987). Assuming exploitation of 20-30 fishing sites, 10-20 individuals daily catch per site and a one-one month fishery season each spring and autumn (50 days/year), the annual sturgeon catch reached about 10 000 - 30 000 individuals along the upper stretch (approximately 450 km long) of the Middle Danube River in the 17th century. The centuries-long excessive fishing continuously truncated the age distribution and reduced the reproduction success of the long-migratory sub-populations. Anadromous sturgeons finally became very rare, and the regular sturgeon fishery terminated along the Hungarian section of the Danube in the 19th century. All catches of anadromous sturgeons in Hungary in the 20th century were less than a higher day to day capture at one sturgeon fishing site in the 16th century. These sporadic catches (at least four order of magnitude decrease) indicate the collapse of populations spawning in the Middle Danube River to the point where their survival was threatened (Hensel, Holčik 1997, Guti 2008).

Habitat loss and degradation of ecological integrity of large river systems are additional significant causes of downtrend in sturgeon populations. The particular habitat requirements of anadromous species, such as the special fluvial spawning grounds and the marine environment during growing phase, as well as the free access to the key habitats within the river basins are altered by human activities in the Danube – Black Sea region:

The suitable habitats for sturgeon reproduction are usually characterised by hard gravel or clay substrate with many crevices, where flow velocities between 0.5-1.5 $m.s^{-1}$ prevail and bed shear stress is generally low (Pirogovskiĭ *et al.* 1989, Reinartz 2002). The former spawning grounds of sturgeons in the Middle Danube River are less known, but some of them can be localised by study of historical documents of fishery, while the environmental conditions can be analysed by historical landscape and habitat assessments. Since the second half of the 19th century, pristine habitat patterns at the historical spawning grounds have been changed by alteration of natural hydro-morphological processes as a consequence of extensive river engineering and improvement of navigability (Guti, Gaebele 2009, Suciu, Guti 2012).

The shelf area of the Black Sea is an essential feeding habitat for sturgeons during their marine life periods. However, in the second half of the 20th century, a four- to fivefold increase in nutrient and organic substances load induced an intensive eutrophication of coastal waters. From the 1970s, eutrophication caused significant loss of fish populations due to temporary appearance of hypoxic and anoxic areas in the 10-40 m depth regions in late summer. Along with threatening the survival of young sturgeons in the sea, hypoxia caused mass mortality of prey organisms and destruction of essential feeding habitats (Bacalbasa-Dobrovici 1997). However, since the 1990s, the conditions have significantly improved due to reduced nutrient inputs (Gomoiu 2010, Zessner 2010), thus favouring sturgeon life in the Black Sea.

The access of anadromous sturgeons to the spawning grounds of the Middle Danube River was interrupted since 1972 by the construction of the Iron Gate I Hydroelectric dam (rkm 943). The migratory route was further shortened by the Iron Gate II dam (rkm 863) since 1984. Only two occasional catches of beluga sturgeon (in 1972 and 1987, most likely slipped through ship locks) were recorded in the Hungarian river section since the operation of the Iron Gate dams (Guti 2008) and nowadays anadromous sturgeons practically disappeared in the Middle Danube River basin.

Conservation measures for recovery of sturgeon populations

The restoration of connectivity is believed to be a high priority requirement in the recovery strategy for the Danube sturgeons (Bloesch *et al.* 2006, Sandu *et al.* 2013). Creating technical facilities for sturgeon passages is an unresolved issue at several hydropower dams, and the design parameters are largely unknown for sturgeons swimming upstream near bottom. A state-of-the-art of measures for ensuring fish migration at dams is given by Pavlov (1989), Larnier *et al.* (2002) and Schmutz, Mielach (2013). The average upstream efficiency of fish pass facilities for non-salmonids is 21% according to an extensive literature review (Noonan *et al.* 2012). Only a few published studies about the sturgeon fish passages are available. In the Volga River system, 10% of the migrating sturgeons were successfully lifted above dams (Gertsev, Gertseva 1999). White sturgeon (*A. transmontanus*) passage was monitored at the Dalles Dam in the Columbia River and eight successful upstream passage events were documented from 90 tagged fish released into the tailrace (Parsley *et al.* 2007). On the basis of literature data, presumed upstream efficiency for sturgeons of future fish passes at the Iron Gate dams may be about 10-20%, which leads to a decrease in abundance of upstream migrants by 95-99% or two orders of magnitude after overcoming both dams. If the functional size of a genetically healthy and viable sturgeon population is assumed minimum 5000 fertile individuals (Lande 1995) and the target abundance of a restored self-sustaining anadromous sub-population in the Middle Danube River, then 100 000 – 500 000 adult individuals guided by homing behaviour would be required downstream in the Lower Danube River to migrate up to the Iron Gate dams.

In parallel to facilitating the upstream fish migration, consideration needs to be given to measures preventing fish mortality during the downstream passage at the hydropower dams. Fish passing through turbines are subject to various forms of stress that are likely to cause high mortality due to mechanical damage, shearing force injuries, and low-pressure conditions. Various techniques are used for reducing fish mortality, such as physical barriers, which appear to be most efficient, while the behavioural barriers are still in an experimental phase and not very promising in large rivers. Development of effective downstream fish passage facilities is a difficult issue (Larinier, Travade 2002), and the existing downstream passage solutions are not suitable for implementation at the Iron Gate dams.

The complete restoration of the free access to the Middle Danube River would not lead to an immediate appearance of anadromous sturgeons and recovery of their reproduction in the upstream river section. Even before the blocking of the migratory routes, catch of individuals migrating up from the Black Sea had already been very rare (Guti 2008), and biological traits, such as longevity and late maturity, cause delay in population recovery. Declining occurrence of long-migratory sub-populations can be explained as a consequence of the Allee effects: In many species, individual reproduction and survival is reduced in small populations through various mechanisms including, for example, a mate shortage (Courchamp *et al.* 2006).

The estimation of effective stocking intensity is an essential requirement in planning a restocking programme for threatened species with regard to the minimum size and structure of their populations, as well as the elimination of the Allee effects. A restocking strategy should consider the mortality of individuals before reaching sexual maturity. Assessments of various sturgeon species by tagging and life history evaluations yielded a general estimate of 5-10% annual natural mortality. The mortality of anadromous sturgeons in the Danube–Black Sea system could be even higher, taking into account

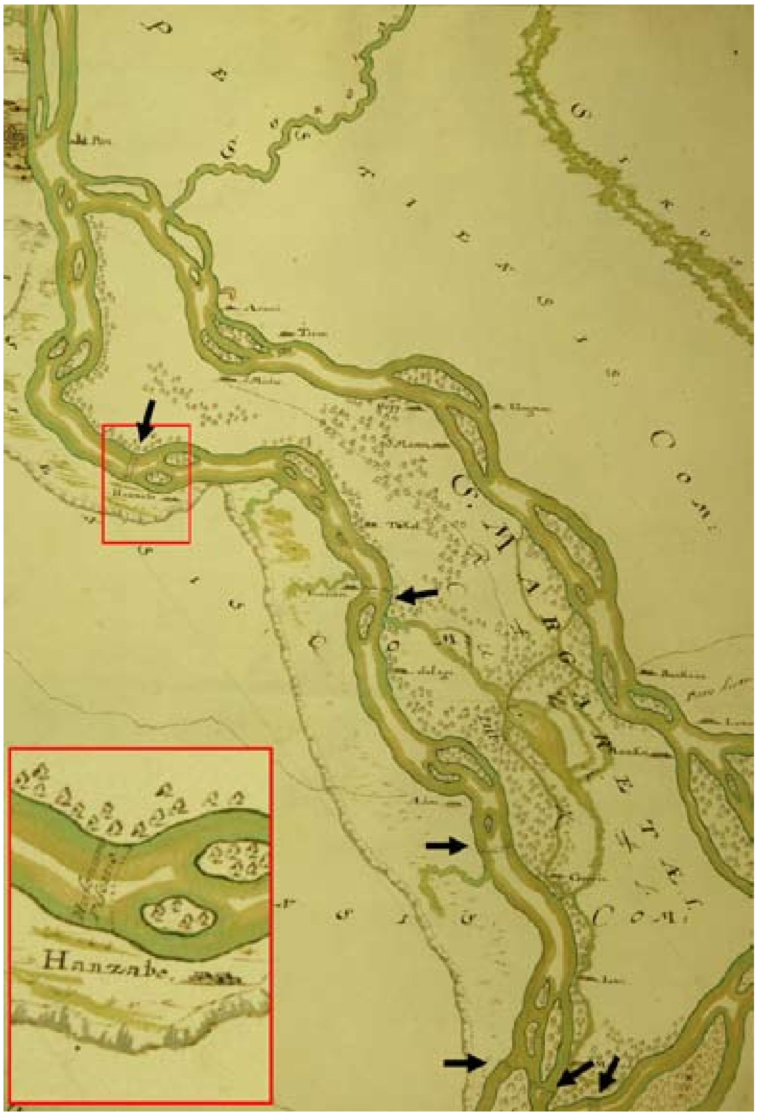

Fig. 1. Marsigli's Danube map downstream of Budapest at the end of the 17th century (a copy of the original map is available in the Danube Museum in Szentendre, Hungary). Six sturgeon fishing sites (Husonum Piscario) are indicated by black arrows within 70 km

the excessive poaching and ecological problems in coastal regions of the Black Sea. However, at a 10% annual mortality rate the overall loss in abundance of stocked sturgeons is about 80% in 15 years, which is around the time of the first reproduction. Therefore, the recommended number of stocked yearlings is 25 000 or five times more than the target abundance of a self-sustaining adult population.

According to rough calculations, less than 20% of Beluga or Russian sturgeon yearlings reach sexual maturity in the Danube River. In this case, stocking of 500 000 – 2500 000 yearlings is necessary for the rehabilitation of an anadromous population in the Middle Danube River. Since the market price of Beluga yearling is 5-10 EUR per specimen, depending on its size, such a stocking programme would cost about 2.5-25 million EUR, however, with more benefits in the Lower Danube River.

Conclusions

Implementation of an extensive sturgeon restocking program may not address the basic cause of population decline, but it can complement the planned general restoration of the ecological integrity of the Danube and Black Sea system. A recovery of anadromous sturgeons encompasses the restoration and creation of suitable spawning habitats in the Danube River. Further, science should investigate whether hatchery-produced individuals are willing to migrate towards upstream breeding sites and show the expected homing behaviour.

Passing the Iron Gate dams across future fish-pass facilities reduces the number of upstream migrants with two orders of magnitude, and technical solutions for successful downstream migration of adult sturgeons are questionable according to our present knowledge. Several questions have not yet been answered; therefore a quick measure implementation for the conservation of the anadromous sturgeons should be focused on the downstream of the Iron Gate dams, where viable populations need to be gradually built up to ensure the necessary number of individuals migrating upstream in the Lower Danube River.

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