Propagation and reintroduction of endangered and commercially exploitable native fish species

An action plan for the conservation of sterlet (*Acipenser ruthenus*) in Hungary

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Introduction

The decline in species richness of native fish fauna, the decrease in fish populations and the narrowing of their distribution area were detectable as early as the 19th century in the larger river systems of Europe (Kottelat and Freyhof 2007). Sturgeon are among the most valuable commercial fishes, but in the second half of the 20th century, their abundance and range began to rapidly decline and now these fish are threatened, critically endangered or disappearing entirely. At the beginning of the 21st century, it became clear that the sturgeon population continued to decline, despite efforts to protect them, so a comprehensive international action plan (Bloesch et al. 2006) was prepared in order to avoid their extinction in the Danube river system. This action plan was also adopted by the Standing Committee of the Bern Convention in 2005.

The adoption of the macro-regional EU Strategy for the Danube Region (EUSDR) in 2011 greatly contributed to the implementation of the international action plan. The aim of the EUSDR is to promote the sustainable development of the Danube macro-region and to protect natural areas, landscapes and cultural values. The strategy, which focuses on 11 priority areas, was developed for the specific challenges affecting the Danube region, two of which are directly related to the protection of sturgeon and migratory fish. One of the objectives of the 4th priority area (PA 4 - Restoration and preservation of water quality) is to improve the protection of migratory fish species in the Danube and to promote measures enabling fish migration in the Danube basin. One of the most important goals of the 6th priority area (PA 6 - Preservation of biodiversity, landscape, and air and soil quality) is the development and implementation of conservation or management plans for the endangered "flagship" species (sturgeon) of the Danube region.

The EUSDR supports the development of transnational cooperation for the purpose of nature conservation, and helped to facilitate the establishment of the Danube Sturgeon Task Force (DSTF) in 2012. The DSTF is an international working group of sturgeon experts, NGO delegates, representatives of the International Commission for the Protection of the Danube River (ICPDR), EUSDR and national governments. The mission of the DSTF is to coordinate sturgeon conservation in the Danube water system and the Black Sea region. The Sturgeon 2020 program was developed (Sandu et al. 2013) by integration with the previous action plan, which, in 2016, the European Commission regarded as a successful initiative of outstanding importance.

The ICPDR, as the administrative platform for the tasks of the Danube River Protection Convention, has been coordinating activities aimed at improving the continuity of the river system, in accordance with the requirements of the EU Water Framework Directive. In connection with this, the importance of the protection of sturgeons and other migratory fish was recognized. The commitment of the ICPDR is highlighted by the inclusion of native sturgeons as an indicator of the ecological status of rivers in the Danube Declaration initiative, which was adopted at the 2016 Vienna Conference of the Water Ministers of the Danube Basin countries. The ICPDR emphasizes the conservation and restoration of sturgeon populations and their habitats in the Danube watershed as important tasks. In order to implement these tasks, a strategy was developed (ICPDR 2018) and cooperation was established with the coordinators of priority areas 4 and 6 of the EUSDR and their partner institutions.

Another important milestone was the publication of the Pan-European Sturgeon Action Plan (Friedrich et al. 2018), which was prepared within the framework of the collaboration between the World Sturgeon Conservation Society (WSCS) and the WWF International. This action plan studied eight European sturgeon species and found that the conservation status of sturgeon species has become extremely critical, with no signs of improvement, indicating that the species conservation programs have not been very successful so far. Four main reasons for the lack of success of existing action plans were mentioned: lack of simplicity, lack of coordination and clear responsibility, lack of public and political awareness, and lack of resources. The new, continent-wide and multi-species action plan aims to provide a framework for preserving the remaining wild populations of sturgeons, restoring their habitats and migration routes, eliminating their illegal fishing and by-catch, and increasing the populations with fish stocking.

International initiatives aimed at the protection of the Danube sturgeons have received remarkable political assistance in the past decade, and several projects were organized with cooperative agreements between research institutions, governmental organizations and NGOs. However, the research on sterlet populations in Hungary is seriously lagging behind its neighboring countries along the Danube. The efforts of sturgeon breeding in Hungary can be considered adequate even by international comparison, contrarily, efforts for the in-situ research into sterlet populations have not received sufficient support.

Sturgeon were once fished in significant quantities in the Danube water system, but today most of their species are critically endangered, with the only exception being the sterlet, which is still moderately common in the large rivers of the Carpathian basin. However, the downward trend observed in the catches of fisheries from the beginning of the 2000s indicates a clear decline in sterlet populations, resulting in the ministerial order on the establishment of certain rules for fish management and fish protection (No. 133/2013. (XII. 29.) VM) which classified sterlet among the "non-catchable" fish species from 2014 onward. In addition to the passive protection measure, a sterlet conservation project was also implemented in 2016 with the support of the Ministry of Agriculture. Within its framework, a program proposal was prepared to increase the sterlet populations in Hungary, resulting in around 18,000 individual sterlet with a length of 40-50 cm being released into some sections of the Danube and Tisza (Józsa et al. 2016).

The study presented here proposes an achievable, realistic action plan for the growth and conservation of self-sustaining sterlet populations, a common interest to fish farms and nature conservation programmes. The biodiversity of fluvial fish fauna is a particularly important part of the natural ecosystem. This biodiversity is endangered by many external anthropogenic pressures and their combined effects. Regarding the conservation status of sterlet and the effectiveness of current measures intended to promote its protection, there is a difference in opinions and interests, which is due, in part, to deficiencies in scientific knowledge. The information available in the literature can be useful in identifying certain misconceptions, but there are still questions to which the current literature and research is unable to give a clear answer. The survival of wild fish populations depends on the implementation of effective protection measures in the coming decades, so the fundamental question is: what can we do now to mitigate future unfavorable changes? This action plan for the conservation of sterlet in Hungary intends to provide guidance in this regard.

Etymology

The origin of the word ‘kecsege’, the Hungarian name of sterlet

The word ‘kecsege’ goes back several centuries. The word 'kechege' appeared in the 14th century Beszterce Glossary, and almost a decade later, and it appeared in the Hungarian-Latin Schlägli glossary made between 1400 and 1410 (Szamota 1894) (Figure 1).

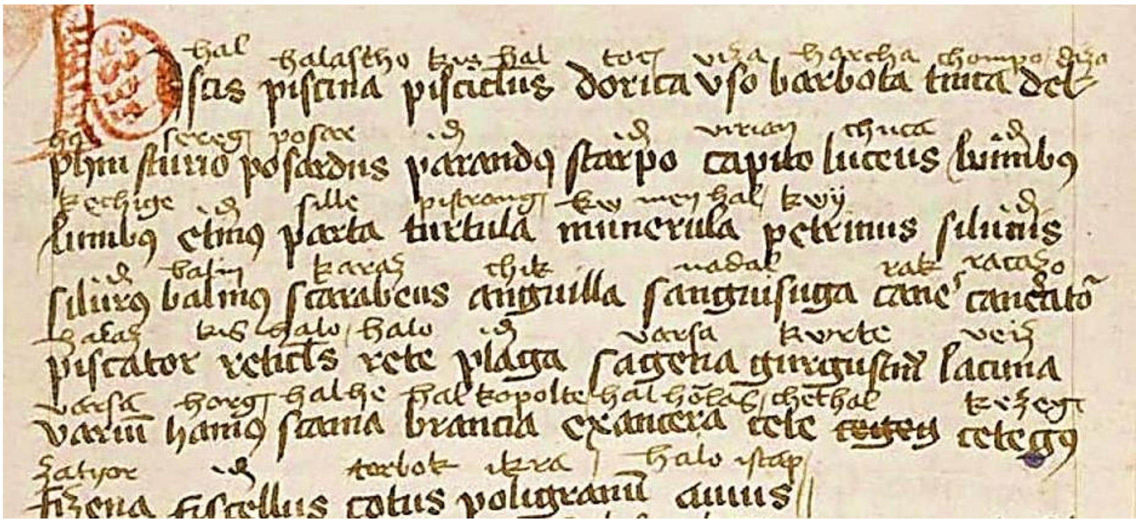

Figure 1: The first section of the Piscis word group in the Schlägli glossary (c. 1400-1410) "kechige" = sterlet, is the first word of the third lowercase line.

The Hungarian word ‘kecsege’ is related to the names cheremisz (súga) and chuvas (súgn), and it is assumed that the Hungarians brought this word to the Ukrainian steppes during their migration since the Ukrainian (kečéga, čečuha) and Russian (čečúga) words can be connected to the Hungarian ‘kecsege’. It was also adopted by the Slovak (kečega), Slovenian (kečiga) and Serbo-Croatian (kečiga, kèčega) languages. Hungarian vernacular versions of the word also exist: kecseg, kecsige, kecsöge, köcsög(e), kecsigetok, etc. (Rácz 1996).

The colloquial name of sterlet in different languages

Table 1 The colloquial name of sterlet in different languages

English	sterlet		
German	kleiner Stöhr	Störl	Sterlett
Russian	чечуга	стерлядь	
Ukrainian	чечуга	стерлядь	
Slovak	jeseter malý	kečega	
Czech	jeseter malý		
Hungarian	kecsege		
Romanian	cega	cigã	
Bulgarian	chiga		
Turkish	çığa balığı		
Serbian	kečige		
Croatian	kèčega		
Slovenian	kečiga		

Taxonomy and evolution

Systematic classification

Based on the current classification of the Integrated Taxonomic Information System, the sterlet belongs to the superclass of ray-finned fish (Actinopterygii), order of sturgeon and paddlefish (Acipenseriformes) and family of sturgeon (Acipenseridae) (ITIS 2021).

- Superclass: Ray-finned fish (Actinopterygii)
  - Class: Basal ray-finned fish (Chondrostei)
    - Order: Sturgeon and paddlefish (Acipenseriformes)
      - Family: Sturgeon (Acipenseridae Bonaparte, 1831)
        - Subfamily: Acipenserinae
          - Genus: *Acipenser* Linnaeus, 1758
            - Species: *A. ruthenus* Linnaeus, 1758

Basal ray-finned fishes (*Chondrostei*)

In previous taxonomic systems, the class of basal ray-finned fishes was separated from other groups of bony fish. According to the Deckert-Sterba system, it is classified in the subclass of ray-finned fishes (Actinopterygia) and within the superorder of primitive swimmers (Palaeopterygii) (Deckert and Sterba 1967). In the new version of Nelson's system, however, it is placed as a subclass branch under ray-finned fishes (Actinopterygii) within the class of bony fishes (Osteichthyes) (Nelson et al. 2016).

The Chondrostei can be considered the remains of a once species-rich group of fish, which may have appeared in the Devonian age of geohistory, and were most abundant in the Triassic age. Their decline began in the Jurassic, and few of their representatives are observed from the Cretaceous period onward.

In the skeletal system of basal ray-finned fishes, the ratio of cartilage tissue is greater than that of bone tissue. Their skull, covered with thick skin bones, is characterized by a beak-like projection (rostrum). During their ontogeny, the spinal chord (chorda dorsalis) remains a defining part of the axial skeleton, which can be considered an ancient characteristic. The beginnings of their vertebrae, the cartilaginous neural and blood arches, are formed. Their mouths are located on the lower side of the head and their jaws are short.

Sturgeon and paddlefish (*Acipenseriformes*)

The ossification of the internal skeleton of sturgeon and paddlefish is not perfect. However, their ancestors had a highly ossified skeleton, so incomplete ossification is not an ancient but a secondary phenomenon (paedomorphosis). At the same time, the structure of their organization is characterized by a number of primitive structural features: a spiral intestinal fold, a large and undivided swim bladder, a spiracle (stunted hole-like gill opening behind both eyes), a heterocercal tail fin, etc.

Fossils of the oldest representatives of the *Acipenseriformes* have been found from the Early Jurassic (201-174 million years ago) (Bemis et al. 1997, Peng et al. 2007, Nelson et al. 2016), when the supercontinent Pangea broke up to form the supercontinents Gondwana in the south and Laurasia in the north. This is the time of the separation of the current representatives of the order, the families of sturgeons (*Acipenseridae*) and paddlefishes (*Polydontidae*), which live in the seas and large rivers of the Northern Hemisphere, comprising subtropical regions, temperate waters and subarctic areas.

Sturgeon (*Acipenseridae*)

Sturgeon are long-lived, late-maturing fish with distinctive characteristics, such as an elongated spindle-like body that is scaleless and armored with five lateral rows of bony plates called scutes; a heterocercal caudal fin composed of diamond-shaped plates (fulcrum) on the distal end ; etc. The surface of their skin is covered by fine bony grains and denticles between the rows of scutes.

The cartilaginous skull is covered by a group of dermal bony plates, the so-called dermocranium. The anterior part of the dermocranium consists of a large number of rostral bones (rostralia). The snout is elongated and either conical or spatulate. The mouth is inferiour, protrusible and toothless in adults, surrounded by fleshy lips and preceded by two pairs of barbels. The dentition develops only in juvenile specimens with the teeth being lost during ontogeny. The gill covers are formed by one strong bone.

Sturgeon fossils date to the Late Cretaceous (100-66 million years ago) (Peng et al. 2007, Nelson et al. 2016). Most species living today are anadromous and migrate upstream to reach river headwaters in their spawning periods; however, sturgeon spend most of their lives feeding in river deltas and estuaries or inhabiting marine environments near coastal areas. Some species have secondarily transitioned to a completely freshwater lifestyle in certain water systems, where their migration is limited to rivers.

The recent representatives of the sturgeons can be classified into four genera: *Acipenser, Huso, Scaphirhynchus, Pseudoscaphirhynchus*.

Acipenser

This genus includes 17 recent species, of which five are North American and the rest are Eurasian (Birstein and Bemis 1997).

Evolution of sterlet

Despite the large amount of fossils that have been found, it is difficult to reconstruct the evolution of sturgeon. In recent decades, numerous studies have been published that attempted to reveal phylogenetic relationships based on molecular methods, but the various studies found partly contradictory results. In relation to the various hypotheses describing the evolution of the phylogeny of sturgeon, a unified expert opinion has not yet emerged (Laumann 2016). Figure 2 illustrates one of the hypotheses. Certain geological processes in Earth's history, such as continental drift (separation of North America and Eurasia, formation of the Atlantic Ocean), presumably influenced the evolution of sturgeon (Peng et al. 2007).

During the Tertiary period of geohistory, the Tethys Ocean, which connected the Atlantic and Pacific basins, continuously contracted with the convergence of the African and European plates. In the Eocene period (56-34 million years ago), the continents were drifting towards their current position. Europe was separated from Siberia by the shallow Ob Sea, and its southern part was still covered by the increasingly narrow Tethys Sea. At that time, representatives of the sturgeon were found in the waters of North America and Europe, but recent species did not originate directly from them (Holčik et al. 1989).

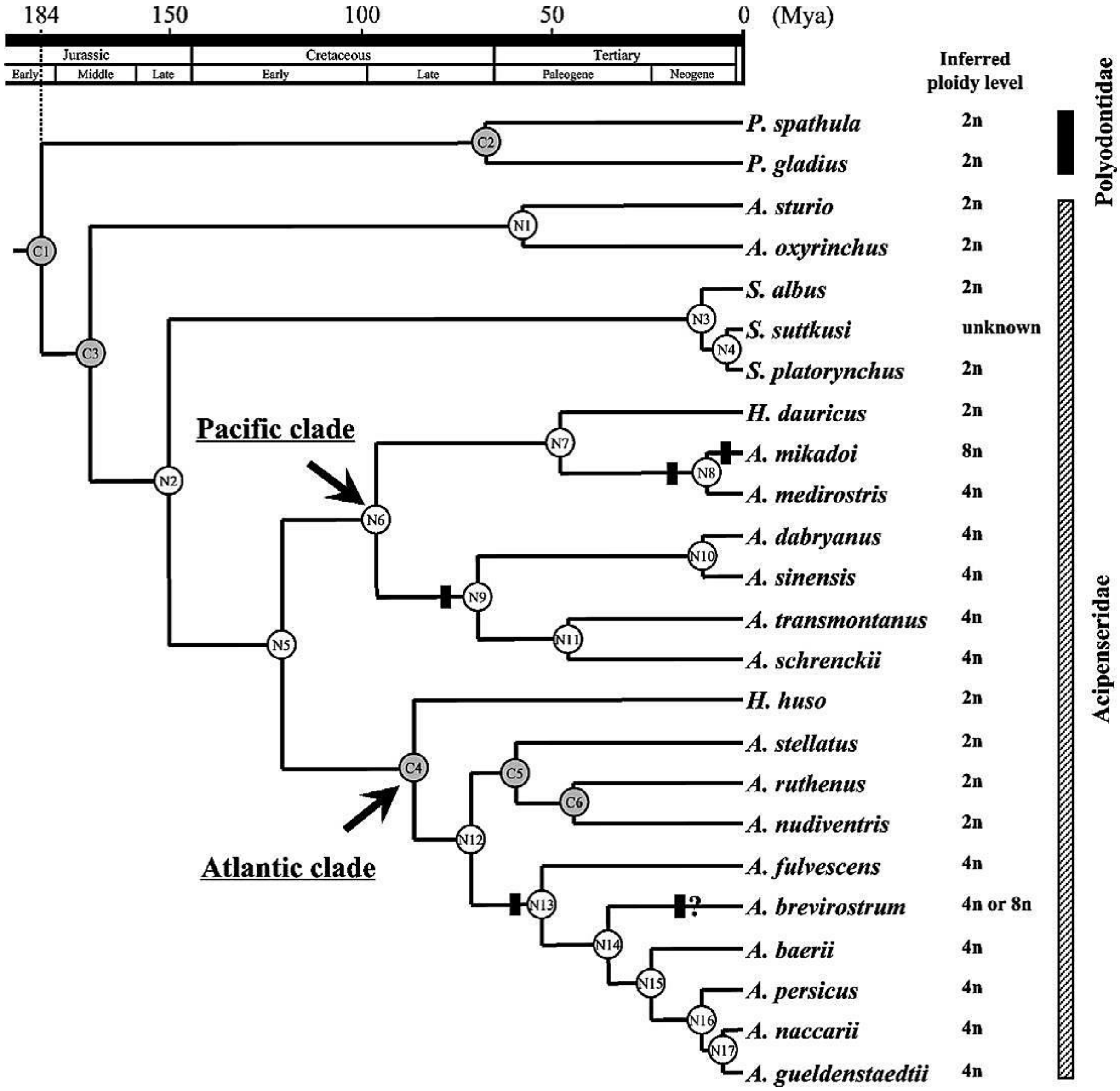

Figure 2: Phylogeny of sturgeon and paddlefish (Acipenseriformes) (Peng et al. 2007)

In Eurasia, the center of the distribution area of *Acipenser* is the present-day Black and Azov Seas, the Caspian Sea basin, and the Aral Sea region, which suggests that their evolution was primarily connected to the Paratethys basin. The Paratethys, which extended from the Alps to the Aral Sea, separated from the Tethys Ocean during the Eocene and Oligocene transition period, about 34 million years ago, as a result of the lowering of the ocean's water level due to climate change and plate tectonic processes.

In the middle Miocene age, about 14-15 million years ago, the African plate collided with Asia Minor, cutting off the connection of the Tethys with the Indian Ocean. The connection of the Tethys with the Atlantic Ocean also narrowed, and this process resulted in the formation of the proto-Mediterranean Sea. At the beginning of the Pliocene period, 5-6 million years ago, the strait (Gibraltar) connecting the primordial Mediterranean Sea and the Atlantic Ocean was also completely closed, so the largest part of the sea dried up as a result of a negative water balance due to evaporation. The desiccation of the inland sea led to an ecological catastrophe, and a significant part of the Paleotropical marine fauna from the Tethys Ocean disappeared. During this dry period, the Paratethys was isolated and had a limited connection with the eastern Mediterranean basin.

With the sinking of the Gibraltar threshold about 5.2 million years ago, the inflowing water mass from the Atlantic Ocean flooded the Mediterranean basin again. During the Pliocene (5.3-2.6 million years ago) and the subsequent Pleistocene period, the connection between the Ponto-Caspian inland seas (mainly the Black Sea and the Caspian Sea) formed from the Paratethys. This connection between the two developed dynamically as a result of water level fluctuations caused by climate change which exceeded 100 meters. During the Pliocene, the salinity of the Ponto-Caspian Seas decreased and became brackish (Holčik et al. 1989, Popov et al. 2006, Yanina 2014).

During the Pleistocene, the fluctuation of the global sea level and the alternation of glacial and interglacial periods dynamically shaped the hydrological conditions and salinity of the Black Sea. During the last 670,000 years of the Pleistocene, the Black Sea came into contact with the Mediterranean Sea 12 times, resulting in high-salinity seawater flowing into the Black Sea through the Bosphorus Strait. At the same time, the Black Sea formed a connection with the Caspian Sea seven times, resulting in low-salt water from melting ice sheets flowing towards the Black Sea (Mamedov 1997, Badertscher et al. 2011, Yanina 2014). After certain glacial periods of the Pleistocene, temporal connections were established between the Caspian Sea and the Arctic Sea region, with the melting ice producing large volumes of water, which was subsequently dammed up by the continuous ice cap in the north. The accumulated water was thus able to flow south, along the valley of the Ob River, across the basin of the Aral Sea and along the Volga valley to the Caspian Sea (Astakhov 2006, Diksha 2019).

At the beginning of the Holocene period (8,000-10,000 years ago), the Black Sea had no connection with any other sea and was freshwater with a reduced water level. Then, 6,000-8,000 years ago, it was again flooded by the salt water of the Mediterranean Sea. This resulted in the freshwater fauna declining with the increasing salinity and ultimately being replaced by Mediterranean marine fauna.

The recent sturgeon species found in this area come from the late Miocene (Pontusian period) fauna of the Paratethys. According to some hypotheses, they survived the dry period of the Pliocene in the Caspian Sea basin, from where they then populated the still fresh-water Black

Sea basin during the Pleistocene (8,000-16,000 years ago), at the end of the Würmian Glacial (Holčik et al. 1989, Mamedov 1997, Birstein et al. 2005). It is also conceivable that sturgeon adapted to the dynamically changing environment, and the evolution of recent species was influenced by genome duplication events (Peng et al. 2007). In some cases, polyploid individuals created by genome duplication could adapt more flexibly to extreme environmental conditions, resulting in complex genotype patterns.

The evolution of the following recent *Acipenser* species is related to the Ponto-Caspian region: *A. ruthenus*, *A. nudiventris*, *A. stellatus*, *A. gueldenstaedtii*, *A. colchicus*, *A. persicus*, *A. naccarii*. Some of these species are spread outside the Ponto-Caspian region, in the western part of Siberia. The direct connections between the water systems of the Caspian Basin and the Arctic Ocean during the Pleistocene allowed their expansion beyond the Ural Mountains and towards the northern European areas.

Description and morphology

The body of the sterlet is elongated, with its maximum height being 5.9-16.6% of the total body length. The head extends long forward, the nose is tapered and curves slightly upwards. The relative length of the head is variable, anywhere from 14.6-30.5% of the total body length. The length of the nose shows considerable individual variation, ranging from 27.8-63.5% of the length of the head.

The mouth opening on the ventral side of the head is relatively small, its width is 12-27% of the length of the head. The lower lip is interrupted in the middle (distinguishing it from smooth ones). The two pairs of fringed barbels located in a line in front of the mouth are long and usually reach the upper lip when smoothed back. There are 2-4 protuberances on the lower side of the nose. The eye is relatively small and does not play a significant role in orientation.

The dorsal scutes are elongated, extending backwards along the apex, and numbering from 11-18. The first back scute is not fused with the head (this feature distinguishes it from *A. nudiventris*). The lateral scutes are small and in contact with each other, numbering from 56-71. The number of abdominal scutes is 10-20. The number of diamond-shaped bone plates (fulcrum) on the distal part of the caudal fin is 25-45. The scutes of young specimens are more developed and sharper, later becoming smoother as the fish ages. The surface of the skin is covered by tiny bony grains between the rows of scutes.

The pectoral fin is well developed and the first fin ray is thickened. The dorsal fin is located close to the tail, above the anal fin. The number of fin rays in the dorsal fin is between 32-49, and in the anal fin there are 16-34 fin rays (Sokolov and Vasil'ev 1989).

Figure 3: Sterlet (*Acipenser ruthenus*) (Photo: G. Guti)

The coloration of the individuals varies, the dorsum is mostly dark greyish-brown with a greenish tint, and the belly is yellowish-white. The scutes are dirty white or have a yellowish tint. The fins are grey and bordered by a narrow whitish stripe. Color variations also occasionally occur: pure white (var. albinea) and orange-pink (var. erythraea) (Antipa 1909, Berg 1948, Janković 1958, Sokolov and Vasil'ev 1989).

The size of the sterlet is smaller than that of other sturgeon species living in the river system of the Danube basin. Its body length rarely exceeds 80 cm and its weight is 3 kg. The size of the largest specimens can reach 100-125 cm and 16 kg.

Certain morphometric characteristics of the sterlet, such as the width and length of the nose, show significant individual variability. Specimens with short and blunt noses were described under the name *A. ruthenus* var. *brevirostris* (Antipa 1909) and *A. ruthenus* m. *kamensis* (Berg 1948) respectively. According to Berg, the migration periods of the different forms vary. The pointed nose sterlet migrates to the spawning grounds in the spring and the blunt nose sterlet migrates in the winter. In the first half of the 2th century, some researchers assumed that the two forms were genetically different and that the blunt-nosed form grows faster and reaches sexual maturity earlier, but this opinion was not confirmed by later studies (Sokolov and Vasil'ev 1989), and the difference in behavior between the two forms cannot be verified either (Janković 1958). The distinction between pointed and blunt nose forms is not always clear and the frequency of transitional forms is also high.

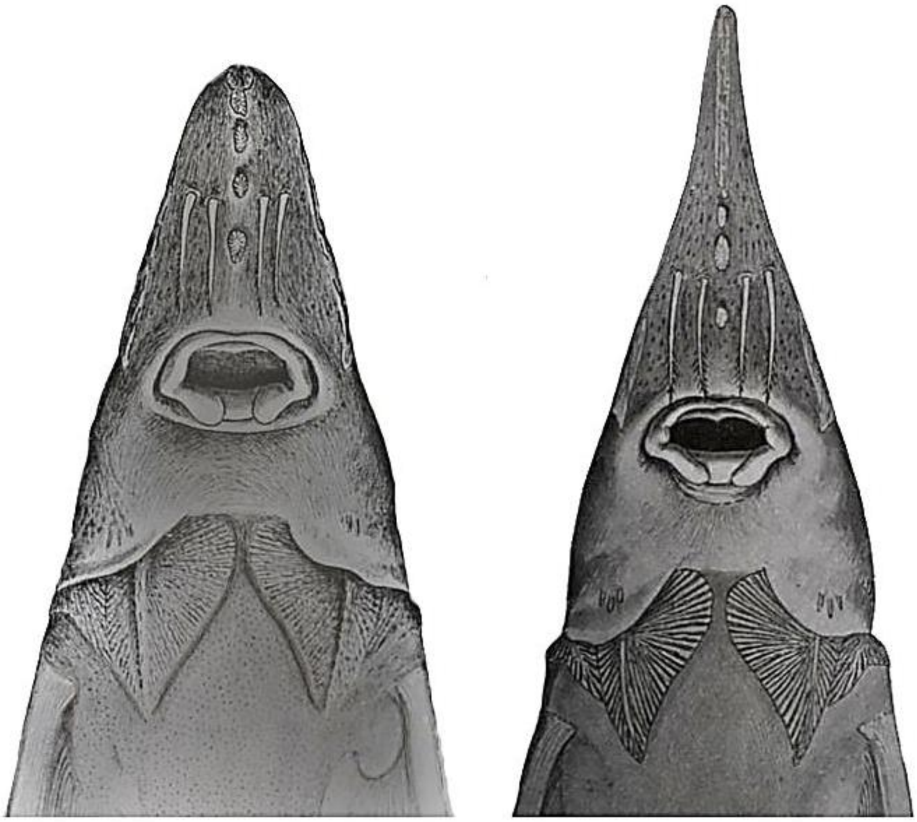

Figure 4: Ventral view of heads of the blunt and pointed snout forms of sterlet (From Antipa 1909)

Distribution

The sterlet is the only Euro-Siberian sturgeon species. The center of its distribution area is the Caspian basin. Its geographical distribution is fragmented and includes:

- the river systems in the northern and western area of the Caspian Sea basin (mainly the Volga and its tributaries, the Ural River and the Kura River)
- the river systems of the northern and western watersheds of the Black Sea and the Sea of Azov (mainly the Danube and its tributaries, as well as the Dnieper, the Dniester and the Don)
- the river water systems of the Kara Sea (marginal sea of the Arctic Ocean) catchment area (the Ob and its tributaries and the Yenisei and its tributaries)
- the Northern Dvina in the southern watershed of the White Sea. According to Nikolski (1943), the sterlet immigration here could have taken place 4,000-5,000 years ago based on the analysis of bone finds

During the Pleistocene, the direct connections between the Caspian Sea and the Arctic Ocean watersheds allowed the spread of sterlet into Siberia and Northern Europe (see the chapter: Evolution of sterlet).

Paleontological findings confirm that in the earlier period of the Holocene, an anadromous population also existed in the northern region of the Caspian Sea, whose individuals grew larger than today's specimens by utilizing the productive marine habitat. The anadromous population became extinct at the end of the 19th century (Sokolov and Vasil'ev 1989) (Fig. 5).

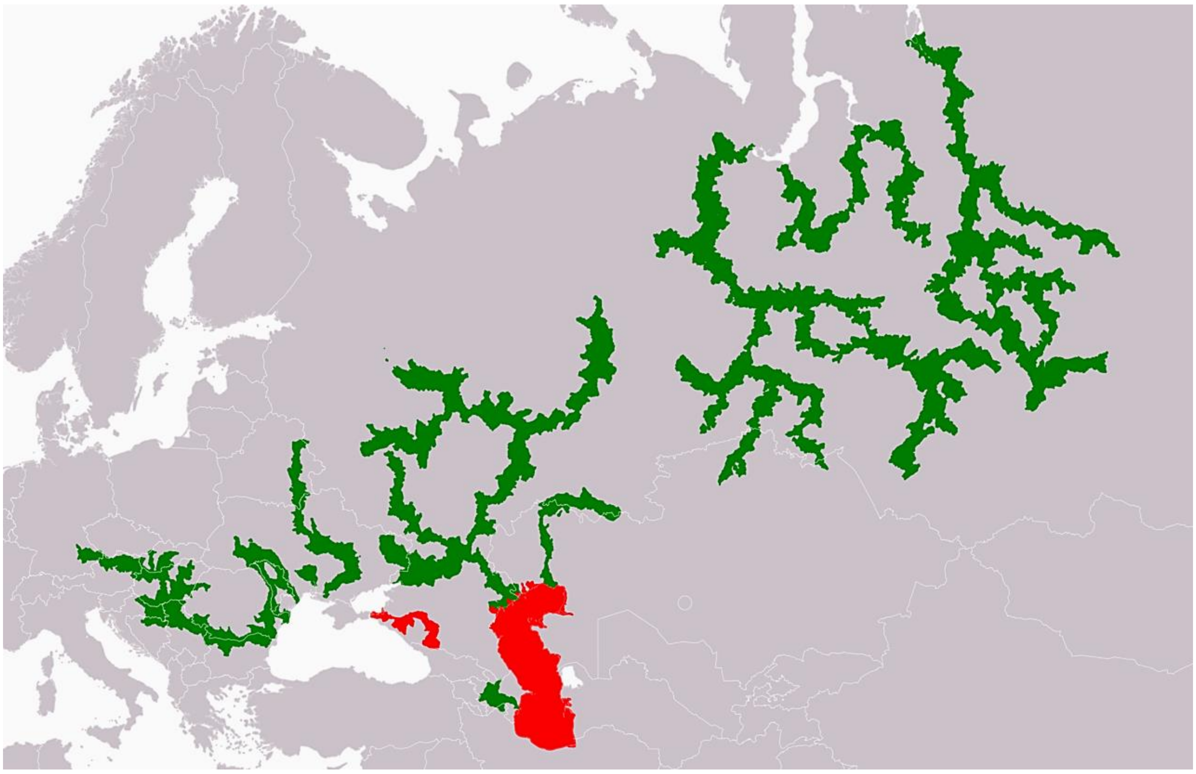

Figure 5: Geographical distribution of sterlet in Europe and Siberia. Red color indicates extinctions. (Gessner et al. 2010)

There have been several introduction attempts outside the natural range of sterlet since the 18th century. The results of the introductions in East Asia (Amur, Kamchatka, etc.) are not known. The sterlet has been successfully settled on the Daugava River in the Baltic Sea watershed, on the Pechora River in the Barents Sea watershed and in the Lake Ladoga (among many others) (Pintér 1989, Kottelat and Freyhof 2007). The occurrence of individuals from aquaculture and ornamental ponds has been detected in many places in Europe, but they have not formed self-sustaining populations (Gessner et al. 2010).

The sterlet is the most common sturgeon species in the Danube basin. It can be found from the Danube Delta to the Upper Danube (Regensburg), and historically inhabited most of the larger tributaries (Heckel and Kner 1858, Herman 1887, Berinkey 1966, Sokolov and Vasil'ev 1989, Hensel and Holčik 1997, Reinartz 2002, Harka and Sallai 2004). Nowadays, the sterlet is almost extinct in the German and Austrian sections of the river, and its distribution has been significantly reduced in the Middle and Lower Danube as well (Hensel and Holčik 1997, Reinartz 2002). Along the Hungarian and Serbian sections of the Danube, fishermen and anglers have caught it in significant quantities in recent decades.

Significant populations have developed in the larger rivers of the Carpathian Basin, but it is only occasionally found in smaller rivers. Taking past observations into account, the natural occurrence of the sterlet is in the entire section of the Middle Danube and the lower section of its larger tributaries (Morava River, Little-Danube, Mosoni-Danube, Raba, Vah River, Hron River, Ipel River, Drava, Mura River, Sava River etc.) as well as in the middle and lower section of the Tisza and the lower section of its larger tributaries (Szamos, Bodrog, Zagyva, Körös and Maros (Herman 1887, Vutskits 1913, Harka and Sallai 2004) (Fig. 6).

Sterlet has also appeared in larger lakes on a few occasions. It fish was observed in Lake Balaton at the end of the 19th century (Herman 1887), when the Siófok sluice was put into operation to control the lake's water level and a significant amount of water was released via the Sió channel towards the Danube (Károlyi 1973). During a major Danube flood, one specimen reached Lake Fertő via the Hanság channel (Faludi 1973). According to archival documents, sturgeon were also caught in Lake Fertő in the 16th century (Hankó 1933).

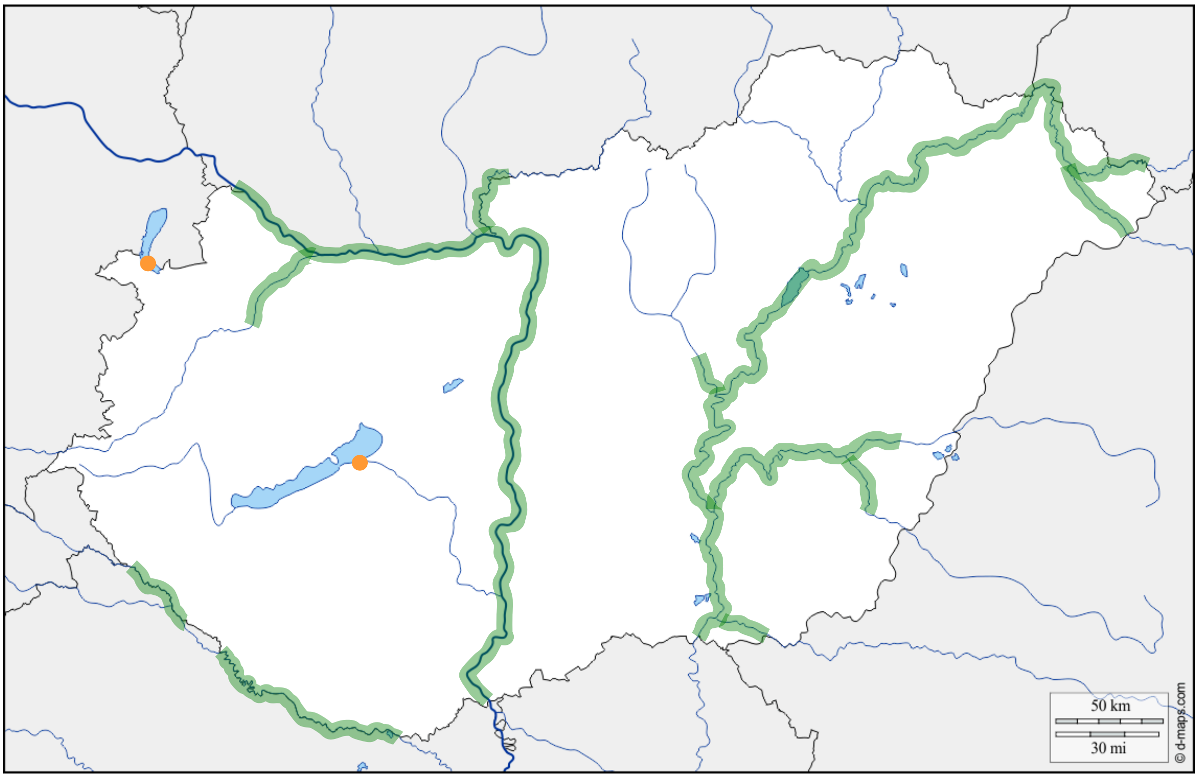

Figure 6: Geographical distribution of sterlet in Hungary (green). Orange dots indicate occasional occurrences.

Ecology

Habitat and migration

The sterlet inhabits the lowland section of larger rivers (potamal region) from the relatively fast-flowing foothill zone (barbel zone) to the slow-flowing meandering section (bream zone). It is usually found in small shoals in deep depressions in the river bed over stony, gravelly, sandy or hard clay bottoms.

The distribution of sterlet populations is usually characterized by stable groupings in free-flowing rivers. For example, along the 650 km long lower section of the Volga, aggregate occurrences of sterlet populations was detected in seven shorter reaches (18% of the entire river section) during the non-spawning period (Kalmykov et al. 2010). In reservoirs, the sterlet usually stays at the upstream end of the dammed river sections, where the hydraulic conditions are similar to those of free-flowing rivers.

The sterlet is a potamodromous species and undertakes a medium distance migration between spawning and feeding areas within rivers. An anadromous population existed until the end of the 19th century in the northern part of the Caspian Sea, which migrated to the Volga in autumn and spawned there in spring (see the Distribution chapter).

Migration behavior towards spawning habitats is regulated in a complex way by external and internal factors. Major external factors are the fluctuation of the river flow, changes in water temperature and quality, changes in the length of the day, etc. Important internal factors are reproduction-related hormonal changes, the physiological condition of the fish, stress levels, orientation ability, etc. Changes in external factors can affect some internal factors (Pavlov 1989, Lucas and Baras 2001, Schmutz and Mielach 2013).

The stages of the migration cycle of the sterlet are:

- Spawning migration - when adult fish gather in schools and move upstream towards habitats suitable for spawning. In the spawning group, there are occasionally immature individuals.
- Post-spawning feeding - when adult fish leaving the spawning grounds usually move downstream in small, loose groups.
- Autumn migration to the wintering grounds - when the fish mostly go upstream in search of longitudinal depressions in the deepest sections of the river bed to spend the winter without eating (Berg 1948).

In the early stages of ontogenesis, the free embryos hatching from eggs reach suitable habitats by passive drifting. Subsequently, fry grow rapidly (with sufficient food) before joining the adult individuals.

In the free-flowing lower reaches of the Volga (about 650 km long from the Volgograd hydropower dam to the Caspian Sea), the sterlet migration was monitored by tracking more than 11,000 tagged individuals between the 1970s and the early 2000s. As a result of the study, it was possible to distinguish three larger populations of sterlet, whose spawning and foraging areas were well separated (Khodorevskaya et al. 2009, Kalmykov et al. 2010). From this study, it was determined that migration towards the spawning grounds takes place in two stages. Adult individuals begin to migrate up the river in July. The intensity of the migration correlated with the temperature of the water. When the temperature cooled to 5-7°C, the migration stopped and sterlets retreated to the deeper depths of the riverbed. Also noted in this study, individuals of distinct geographic populations migrated different distances during the autumn period. Sterlet from the western part of the Volga delta migrated less than 100 km, while individuals from the eastern part of the Volga delta migrated up to 200 km. The migration continued in the spring towards the upstream spawning grounds. The intensity of migration from April to mid-May showed a correlation with water temperature (r=0.62) and turbidity (r=0.53), as well as with the water level of the river (r=0.50). The average fish swim speed of the 150 km long, 20-25 day spring migration was 6.2 km/day.

The distance covered during the autumn and spring migration of the distinct sterlet populations differed significantly: the fish from the western part of the Volga delta migrated to spawning grounds located 250 km upstream, while the fish from the eastern part of the delta migrated 350-400 km. The migration of a third distinct population living below the Volgograd dam covered a distance of 150 km. The separation of the spawning grounds could be verified, but not the overlap, even though the migration route of one population passed through the spawning grounds used by the other population. Those individuals that did not migrate to the spawning grounds stayed in the foraging area in the spring as well (Khodorevskaya et al. 2009, Kalmykov et al. 2010).

The post-spawning migration is directed towards river sections richer in food. In the Volga, sterlet search for feeding habitats where the biomass density of benthic organisms exceeds the values found near the spawning grounds by about 20 times. The speed of downward post-spawning migration is significantly slower than the spawning migration. By tracking the movements of individual sterlet, it was shown that the migration from the end of May to September becomes more intense as the water temperature rises and reaches its peak at the end of July. The number of migrating individuals increased during the period of receding floods and at water temperatures of 18-20°C, but decreased at low water levels and at water temperatures above 22°C. The speed of their movement was also influenced by the food supply of each river section; where the density of benthic organisms was higher, their migration slowed down and they spent more time feeding (Kalmykov et al. 2010).

During the period of early individual development, the free embryos hatching from the eggs lie on their sides on the surface of the bottom of the river bed and occasionally swim up from the substrate and drift with the flowing water before sinking back to the bottom. Passive drifting at a speed of 15-20 km/day lasts for 3-8 days, until the beginning of active feeding. Depending on the length of spawning, the period when drifting embryos can be detected may vary. On the Volga, this usually occurs over a period of 20-30 days, from the end of May.

As the larvae begin to actively feed, they move away from the substratum less and less, turning to face the water flow and moving lively to maintain their position. In contrast to the behavior of larvae of anadromous sturgeon species, the downstream migration of the sterlet larvae takes place near the substrate and not in the water column. Larvae usually gather in groups in the depressions in the riverbed at a depth of 8-21 m, where they are protected from the water flow (Kalmykov et al. 2010).

Figure 7: One of the typical habitats of sterlet in the Danube River Basin: bream zone (Photo: G. Guti)

According to the results of mark-recapture surveys carried out in the Danube, the marked sterlets generally did not migrate further than 200 km (only in exceptional cases were they were found 300 km downstream from the location of their marking). The speed of the individuals' migration downstream can reach 7-23 km per day (Unger 1953, Ristič 1970).

In a monitoring program carried out between 1992 and 1995 on the Slovak-Hungarian section of the Danube, fish migration was investigated based on the catch data of fish marked with external fish marks (Floy T-bar anchor). During the survey, 2 specimens of 204 marked sterlets were recaptured, one 1 month later, near the marking site and the other 13 months later, 10 km upstream from the marking site (Holčik et al. 2006). Later, from 2016 to 2017, sterlet migration was monitored using acoustic telemetry on a 34 km long river section between Žitava (Zsitvatő) and Esztergom (1752-1718 fkm). These monitoring results confirmed that migratory activity begins in the spring when the water temperature reaches 12°C and ceases when it rises above 22°C during the summer months. In autumn, migration activity ends when the water temperature drops below 12°C (Kubala et al. 2018). Changes in day length can also affect fish migration, although there is a significant correlation between day length and water temperature, so it is questionable how decisive the effect of day length is.

Reproductive biology

Genital organs and gametes

Sexual dimorphism is not typical in sterlet, although among the individuals ready to spawn, females can be recognized by a looser and larger belly. However, less definite morphological differences have been detected in some populations. For example, male sterlet from the Tisza River have been known to have pectoral and ventral fins that are shorter than those of females (Vladykov 1931). Another example of morphological differences is seen in the males from the Slovak section of the Danube which have a slightly longer nose, shorter external barbels, shorter dorsal and caudal fins, and more lateral scutes than in females; but these differences are not statistically significant (Holčik 1995).

The male and female sexual organs can be distinguished by histological methods from the age of 4-9 months. The duration of sexual maturity may vary in different river systems. Males spawn for the first time at 3-6 years of age and females from 5-8 years of age (Sokolov and Vasil'ev, 1989). Males usually breed every year while females typically breed every two years (Janković 1958).

The sterlet ovary is not covered by epithelial tissue, so the mature oocytes enter the body cavity after ovulation. During spawning, the egg reaches the outside world through the cone-shaped oviduct which extends into the body cavity. The average total weight of the eggs of smaller females (weighing 0.25-0.5 kg) is 80 g, while that of larger specimens (weighing 2.5-3.0 kg) is 560 g, on average (Janković 1958). The number of mature eggs in the ovary can vary between 4,000 and 150,000. The ratio of mature eggs to female body weight (relative fecundity) is 12,400-35,300 eggs/kg (Shmidtov 1939), which is relatively high compared to the larger sturgeon species. The ripe egg is slightly oval in shape and gray-black in color with its size varying from 2.01 x 1.85 mm to 2.86 x 2.77 mm (Janković 1958).

The sterlet testicle extends from the anterior end of the swim bladder to the final, spiral section of the intestinal tract, while its two lobes are separated by the swim bladder. The lobes are fixed on the dorsal side of the body cavity and on the surface of the kidney. Unlike bony fishes, the testicular ducts are closely related to the kidneys. During sperm production, the mature sperm are discharged into the testicular ducts which pass through the kidneys and are then released into the outside world through the urethra. Due to the direct connection between the testicles and the kidneys, the spermatozoa come into contact with urine even in the testicles, which is why the sperm are much more diluted (1 billion sperm/cm^3) than in the case of bony fish. Sperm with a size of 5-6 µm are activated when released into the water and remain viable for a relatively long time, depending on environmental conditions.

Spawning

In early spring, the sterlet appear in groups at the spawning grounds located in the more upstream sections of the rivers. According to observations made in the Kama River (a tributary of the Volga), males are the first to arrive near the spawning ground when the water temperature is around 9-11°C; females arrive after the males, when the water temperature warms to 12-13°C. The proportion of males in the spawning area is 60-70%. Spawning lasts, with minor interruptions, from the beginning of April to the end of May, sometimes until the middle of June. During the spawning period, the water temperature can vary from 8°C to 19°C in the Middle Danube, with the most favorable spawning water temperature being 12-17°C. If the temperature rises above 20-21°C or falls below 9.4°C, spawning is interrupted. The details of group spawning are less well known. After laying the eggs, the females immediately leave the spawning place, while the males remain in the area and fertilize the eggs of several females, which adhere to the substrate. Spawning individuals do not feed during the breeding season (Shmidtov 1939, Lukin 1947, Janković 1958).

The selection of the spawning site can be influenced by the dynamics of the river water level and the intensity of spring floods. In the spawning grounds, which are usually located at a depth of 7-15 m, the water flow speed typically exceeds 1.5 m/s. The substrate is composed of gravel with a grain size of 1-7 cm and is free of fine-grained silt. In the area of the investigated spawning grounds in the Káma River, the oxygen content of the water varied from 6.86-8.31 mg/l (Shmidtov 1939). Spawning grounds have been identified on many rivers, where shoals of sterlets regularly spawn each year. In other places they only appear in certain years during the breeding season, usually depending on water levels. If fine-grained sediment is deposited on the substrate at a previous spawning site, the sterlet will leave the area.

Early individual development

The duration of early individual development depends significantly on the water temperature. Hatching begins after 6-7 days at a water temperature of 13-16°C, which is considered optimal for egg development, and after 4-5 days at 16-18°C. As the temperature rises, the frequency of abnormalities increases, negatively affecting embryonic development (Chebanov and Galich 2013).

Figure 8: Free embryo of sterlet (non-feeding larva)

The free embryo (non-feeding larva) is 8-9 mm long and weighs 0.008-0.011 g. The free embryo stage lasts 5-15 days, depending on the water temperature. Upward-moving embryos drift to slow-flowing bed sections before beginning independent feeding. The larval stage begins with the absorption of the yolk and the beginning of independent feeding. At this stage, a darkcolored, stick-like plug of melanin leaves through the anus, which is formed from pigment particles that accumulate in the back of the alimentary canal during embryonic development.

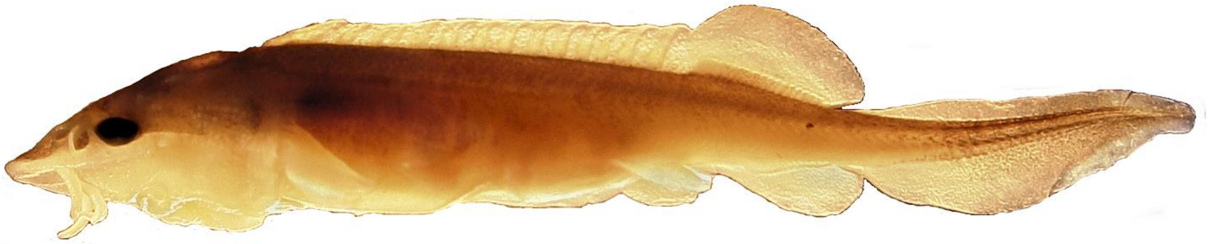

Figure 9: Sterlet larva on the 27th day after hatching: body lenth 30.7 mm ($TL_{DAH\ 27}$ 22.8-40.3 mm, $w_{DAH\ 27}$ 0.055-0.350 g). The formation of lateral scute lines is completed. The remains of the fin fold can be observed between the indentations of dorsal scutes (Rybnikár et al. 2011).

Figure 10: Sterlet larva on the 30th day after hatching: body lenth 35.3 mm ($TL_{DAH\ 30}$ 24.0-47.6 mm, $w_{DAH\ 30}$ 0.075-0.566 g). The fin fold begins to disappear between the dorsal scutes. The fin rays begin to form in the dorsal and caudal fin (Rybnikár et al.2011).

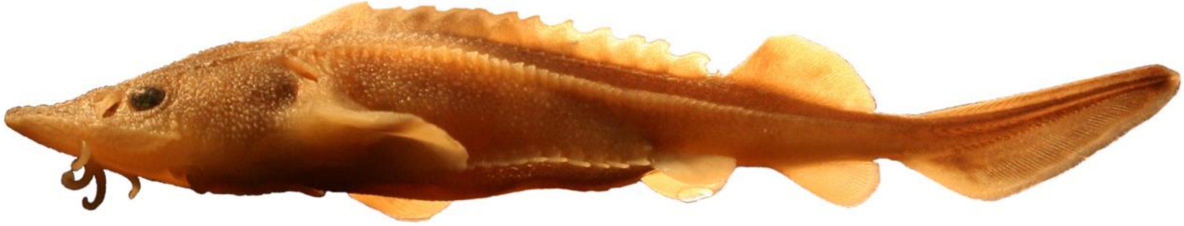

Figure 11: Sterlet larva on the 37th day after hatching: body lenth 57.0 mm ($TL_{DAH\ 37}$ 26.2-63.7 mm, $w_{DAH\ 37}$ 0.095-1.263 g). With the disappearance of the fin fold, the larval stage ends. The fin rays of the dorsal, caudal and anal fins extend to the edge of the fin, the fin rays of the ventral fin are already visible. Rybnikár et al.2011).

Figure 12: Sterlet juvenile on the 69th day after hatching: body lenth 111.4 mm ($TL_{DAH\ 69}$ 89.5-114.7 mm, $w_{DAH\ 69}$ 4.378-7.767 g). The differentiation of the caudal fin continues. The skin pigmentation and the development of integument are significant (Rybnikár et al. 2011).

The body length (TL) of free embryos developing in 18°C water on the 5th day after hatching (DAH 5) $TL_{DAH\ 5}$ is 13.1–15.3 mm and the body weight (w) $w_{DAH\ 5}$ is 0.012–0.019 g. At this stage, the melanin plugs begin to appear, but no external food is yet visible in the digestive system. Initial pectoral and ventral fins are visible and a continuous odd fin fold stretches over the body. On the 10th day after hatching (DAH 10), the $TL_{DAH\ 10}$ is 14.5–18.6 mm and the body weight (w) $w_{DAH\ 10}$ is 0.015–0.033 g. In addition to the removal of melanin plugs, external food in the digestive system becomes visible in some individuals. The differentiation of odd fins is more pronounced. The initiation of independent feeding is a critical stage of individual development. On the 13th day after hatching (DAH 13), the $TL_{DAH\ 13}$ is 14.8–20.5 mm and the body weight (w) $w_{DAH\ 13}$ is 0.013–0.047 g. External food can also be observed in the digestive system of all individuals at this stage (Rybnikár et al. 2011).

Feeding

The primary food source for sterlet consists of benthic organisms found on and near the substrate. Among these, aquatic insect larvae are the most important, such as chironomids (*Chironomidae*), caddisflies (*Trichoptera*), mayflies (*Ephemeroptera*), blackflies (*Simulidae*), stoneflies (*Plecoptera*), as well as smaller molluscs (*Spherium*, *Pisidium*, *Viviparus*, etc.), annelids (Oligochaeta, Polycheaeta, Hirudinea) and other invertebrates (Sokolov and Vasil'ev 1989). When there is a mass swarm of mayflies and stoneflies, it can be observed that sterlet jumps out of the water and catches flying insects in the air. Considerable quantities of planktonic crustaceans (*Cladocera*, *Copepoda*) were found in the stomach of sterlets living in the larger reservoirs of the Volga (Lukin et al. 1981). The young individuals mostly feed on the larvae of chironomids and caddisflies, during their growth the consumption of caddisflies comes to the fore. In the area of the Volga delta, the dominance (90%) of amphipods (*Gammaridae*) among the food sources of sterlet juveniles was observed (Polyaninova 1972). Sterlet may occasionally feed on larger quantities of fish eggs, including sturgeon eggs (Khoroskho 1967). Sometimes, smaller fish make up a component of sterlet food sources (Aristovskaya 1954, Nagy 1987, Fieszl et al. 2011). The most important food competitors of the sterlet in the Volga are: ruffe (*Gymnocephalus cernua*), bream (*Abramis brama*) and white bream (*Blicca bjoerkna*) (Aristovskaya 1954).

In Danube section between Komárom (Komarno) and Šturovo, 46 types of food components were identified in an analysis of sterlet stomach contents collected in the latter half of the 1950s. Benthic aquatic insects predominated among the organisms consumed, mainly the larvae and pupae of chironomids, as well as the larvae of mayflies and caddisflies. The frequency and quantity of the Danube flower (*Epheron virgo*) was high among the mayflies. A small difference was detected in the composition of the food of male and female individuals. Females consumed annelids (Oligochaeta) more often, while males had a higher proportion of rheophilic insect larvae living in running waters. Based on this difference, it can be concluded that the foraging area of the females extends to the slower-flowing river sections and non-flowing tributaries, where the substrate is covered by finer grain size sediment (Nagy 1987). In the stomach content of sterlets examined at the beginning of the 1990s and in the section of the Danube between Nagymaros and Vác, the larvae of caddisflies and chironomids, as well as amphipods, were the most numerous food components. All fish remains found in the stomach contens of sterlet were identified as barbel (*Barbus barbus*) fry (Fieszl et al. 2011).

Population dynamics

Age distribution, growth, mortality

The sterlet is considered a short-lived species within the genus *Acipenser*. The oldest known specimen was 27 years old, which was caught in the Kujbisev reservoir on the Volga (Lukin et al. 1981). Based on studies of several populations, it can be concluded that females live significantly longer than males (Sokolov and Vasil'ev 1989). There are significant differences in the growth of sterlet in different river systems (Figure 13). A relatively rapid increase in body length was shown in the Serbian (formerly Yugoslav) section of the Danube, especially for the pointed-nosed form (Janković 1958). The growth rate of the pointed and blunt-nosed forms can be distinguished in other populations. The growth of the Tisza population can also be considered rapid (Györe and Váry 1993), while the Central Volga population is characterized by slower growth (Lukin 1937). Sterlet grows faster in dammed sections of the Volga, such as the area of the Kujbyshev reservoir, than in river sections not affected by damming (Lukin 1937, Lukin et al. 1981, Gurov 1966), presumably due to the warmer water temperature.

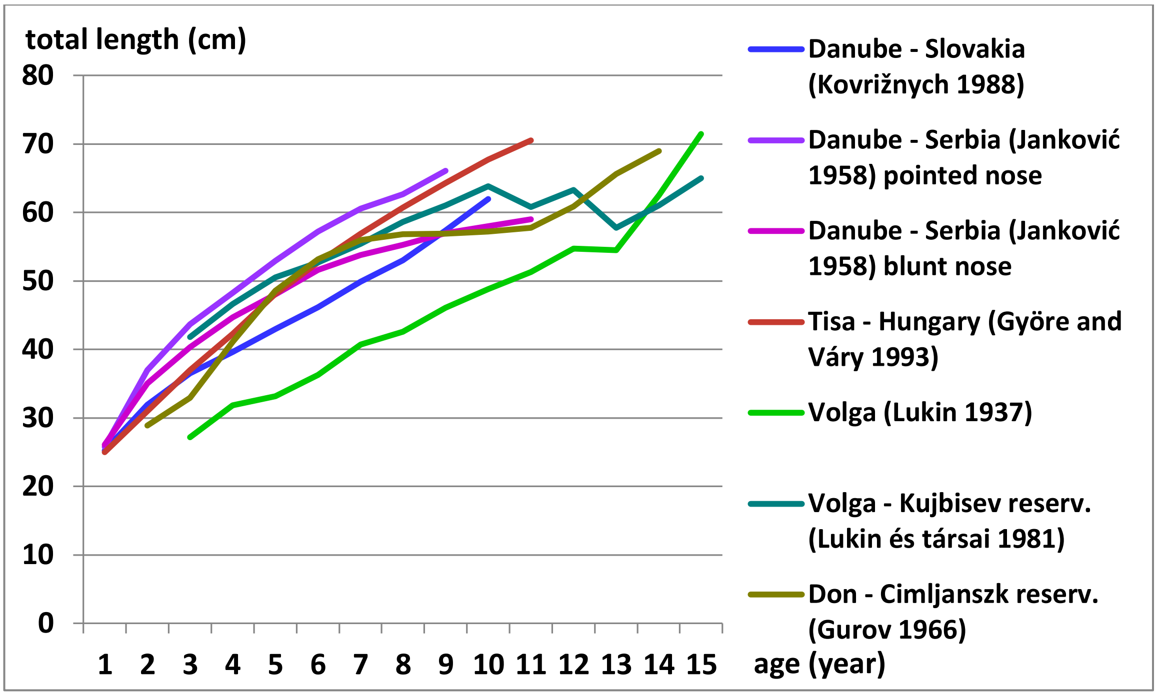

Figure 13: Annual increase in body length of sterlet in different water areas

Larger specimens, longer than 100 cm, are rarely found. Among the 458 individuals collected in the Tisza, the largest specimen was 72 cm long, 2.45 kg in weight, and 11 years old (Györe and Váry 1993). Among the catches published by the Hungarian anglers, the largest reported was a 9.98 kg specimen in the Tisza, which was caught near Tiszabezdéd in October 2019, and a 9.20 kg specimen in the Danube, which was caught at Dunabogdány in August 2022. During a scientific survey in the Slovak-Hungarian section of the Danube in 2016, the length of the largest specimen was 92 cm and its weight was 8.05 kg (Kubala et al. 2018).

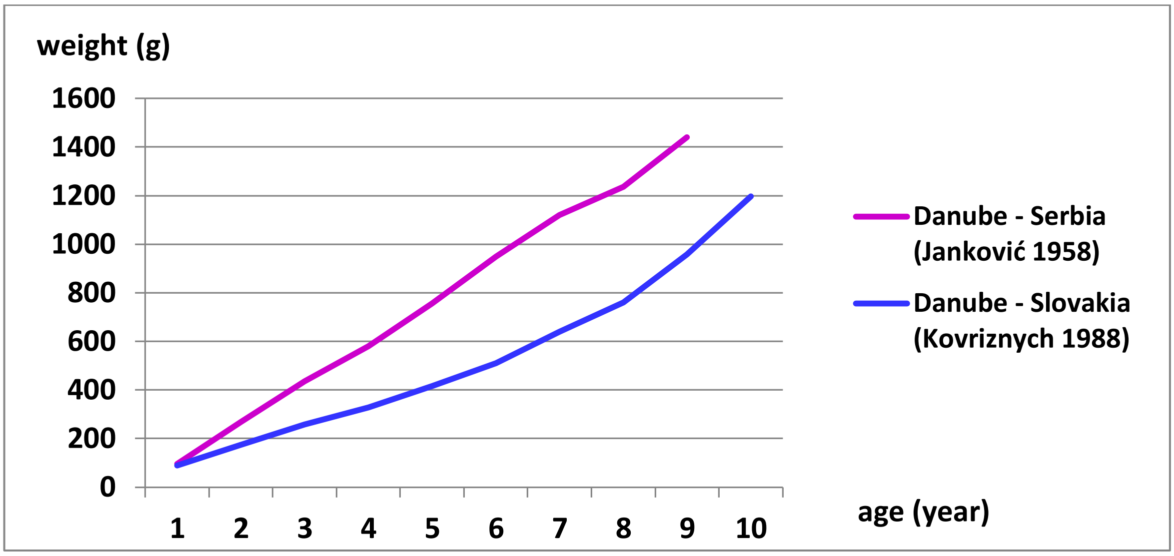

Figure 14: The annual increase in the body weight of sterlet in the Slovak-Hungarian and Serbian sections of the Danube

The relationship between the body length (Lt) and body weight (w) of the pike is described by the following equation (in cm and g units) based on the measurements carried out in the Slovak-Hungarian section of the Danube (Holčik 1983):

$$w = 0{,}0143 * L_t^{2{,}86275}$$

In Hungary, knowledge on the dynamics of sterlet populations is generally characterized by a lack of data. Based on samples collected between 1987 and 1991 (n=496) in the Tisza between Csongrád and Szeged, the highest (55%) frequency characteristics of sterlet caught by a commercial fishery was a body length of 47-55 cm and an age of 5-6 years old. Due to the selection of certain fishing gear, the proportion of younger age groups (2-3 years) in the catch was low (6%). The estimated biomass of the 5-11 year age groups was 6.49 kg/ha, and the fishing yield was 1.77 kg/ha in the 85 km long river section. Both values can be considered high compared to the stock estimates carried out in the river sections upstream of Csongrád (Györe and Váry 1993).

Based on the analysis of age distribution data (Janković 1958) on sterlet (n=1,246) collected in the Serbian section of the Danube in the 1950s, the average annual survival rate for age groups 3+ to 10+ is 54% (S=0.54). This data is used for the estimation of the annual growth of sterlet, the relationship between their body length and body weight, and the annual survival rate for different age groups. From these estimated parameters, the theoretical changes in biomass for successive age groups can also be determined (Guti 2008). For example, a biomass of 10,000 individual juvenile sterlet (age 0+, average length 10 cm, average weight 8.7 g) is expected to be about 350 kg (210-550 kg, 95% confidence level) after five years (5+) (Figure 15). The theoretical changes in biomass gives an indication of the expected impact of fish stocking on the overall population.

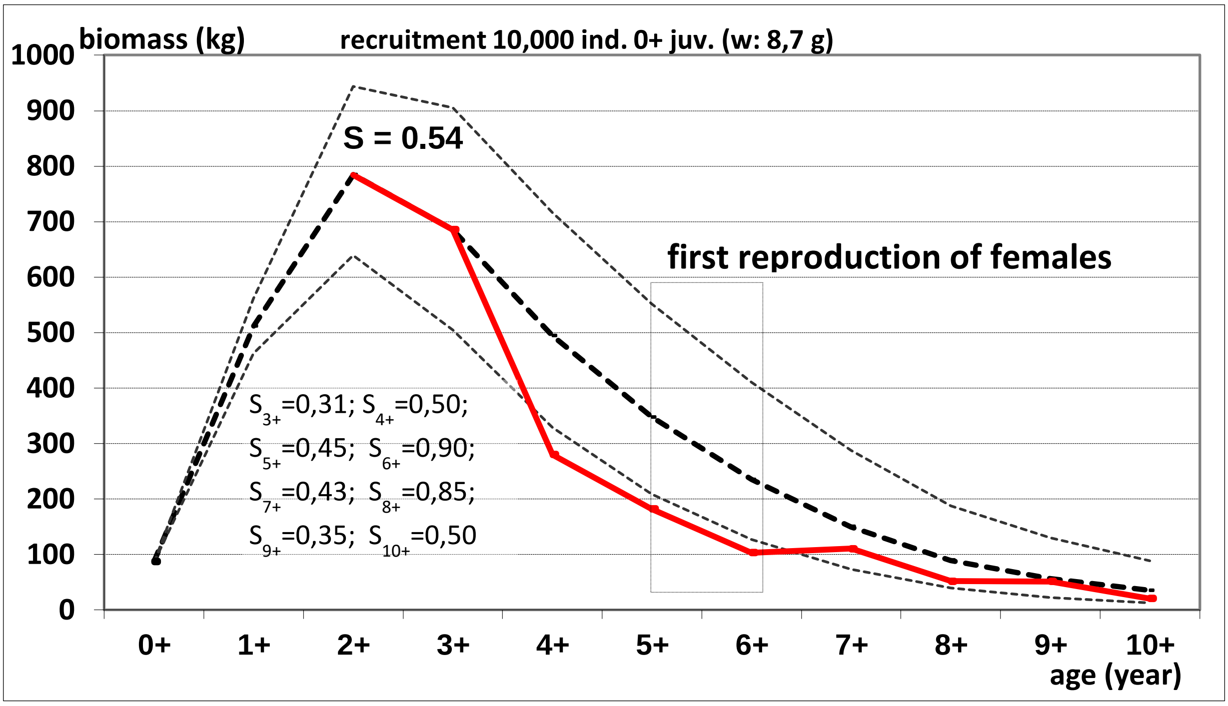

Figure 15: Change in the biomass of 10,000 individuals of sterlet fry (0+) over 10 years. Solid red line: biomass calculated according to the age distribution observed in the 1950s. Dashed line: calculated biomass if survival rate is 0.54, thin dashed line: 95% confidence interval. The difference between the theoretical and observed values is most likely a result of the impact of fishing activities.

Long-term changes in sterlet populations in Hungary

In Hungary, a suitable monitoring system for the study of sterlet populations does not exist, unlike the research practices of most countries along the Danube (Guti 2021). In the absence of direct surveys, the long-term changes in sterlet populations in Hungary can only be characterised, to a moderate extent, by analysing catch data from fisheries and angling (Guti 2008, 2014, Guti and Gaebele 2009, Suciu and Guti 2012). In the fish catch database in Hungary, the amount of sterlet caught was not significant, amounting to 0.99% of the total fish catch, with a decreasing trend in the decade between 2004 and 2013. In this period, 60% of the total sterlet catches came from the Tisza, 24% from the Danube and 16% from other rivers (Figure 16). Catches were characterized by a decreasing trend in all water bodies during this time period.

Aggregate data on anglers' sterlet catches on the Danube and Tisza rivers have been kept since the mid-1950s (Figure 17). Significant fluctuations can be observed in the data series of both water systems, with little similarity between them. In the Danube, annual catches were mostly below 500 kg from the mid-1950s to the mid-1970s, then it tripled in the mid-1970s and generally exceeded 1,500 kg by the end of the 1980s. Afterwards, catches fluctuated mostly between 1,000-1,500 kg in the 1990s, and for a short period in the mid-2000s the amount caught exceeded 2,000 kg before falling below 1,000 kg by the early 2010s.

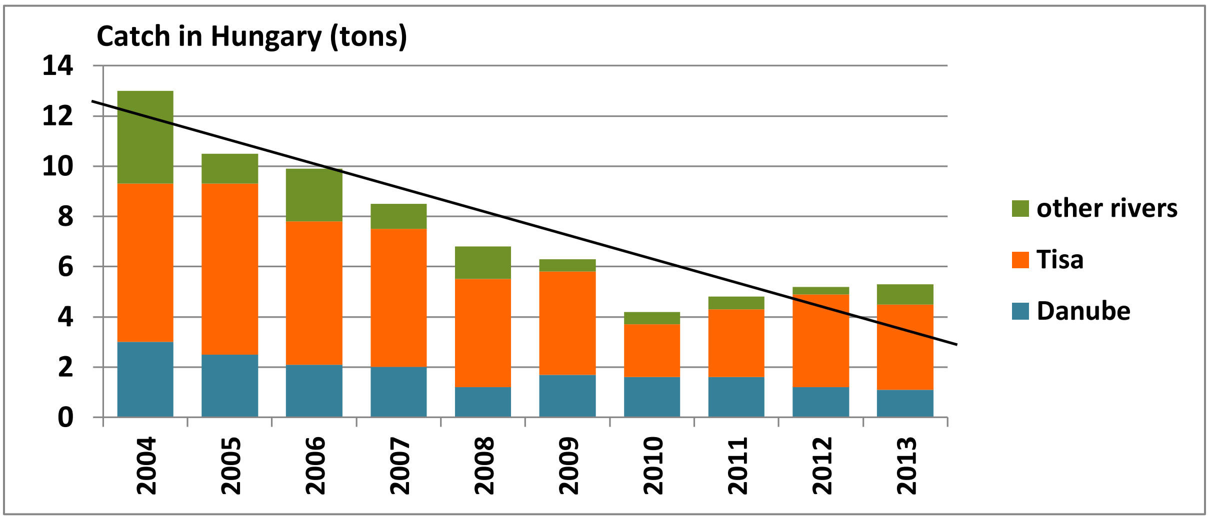

Figure 16: The downward trend of the sterlet catch (fishermen and anglers) in Hungary in the period between 2004 and 2013 (based on the OHA database)

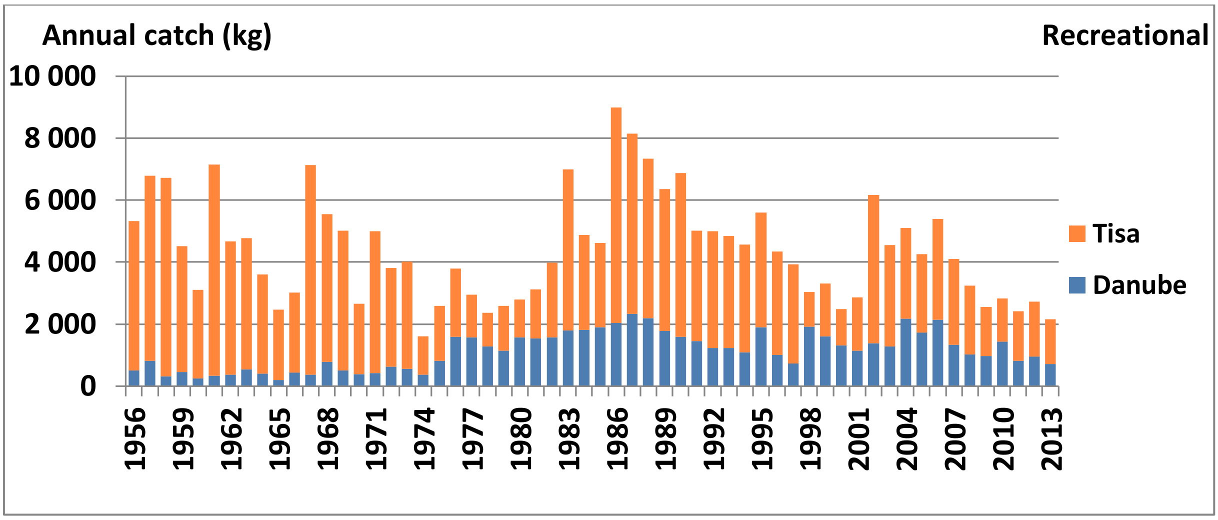

Figure 17: The anglers' annual catch of sterlet in the Danube and the Tisza in the period between 1956 and 2013. (based on MOHOSZ and OHA database).

In the Tisza, from the mid-1950s to the beginning of the 1970s, the sterlet catch fluctuated between 2,000 and 7,000 kg annually. In general, the sterlet catch was six times (in some years even twenty times) higher than the catches of Danube anglers. From the mid-1970s to the beginning of the 1980s, the catches fell to 1,000-2,000 kg. A significant increase started in the first half of the 1980s, with catches exceeding 3,000 kg (in some years approaching 7,000 kg) before a downward trend began in the 1990s. In the first half of the 2000s, catches fluctuated between 1,000 and 2,000 kg and gradually rose to over 4,000 kg. Then, from the second half of the decade, catches fell below 2,000 kg with a continuous downward trend until the 2010s.

Anglers' catch data gives a limited indication of the quantitative changes in the sterlet population due to the following reasons: 1) the number of fishing days showing the intensity of angling activity in recent decades is not known, 2) the amount of fish that can be caught by fishing is regulated by quotas, therefore the amount of catches exceeding the quota is not known, 3 The original role of angling, the search for food, is increasingly being replaced by recreational fishing; therefore, anglers release some of the fish they catch, regardless of the quota, and their quantity is also unknown.

Data from commercial fisheries reflects the evolution of fish stocks in a different way. Fishermen's equipment and number of employees changed little over the long term, and quantitative quotas did not limit their catches. However, little data is available on the changes in, and intensity of, commercial fishing activities.

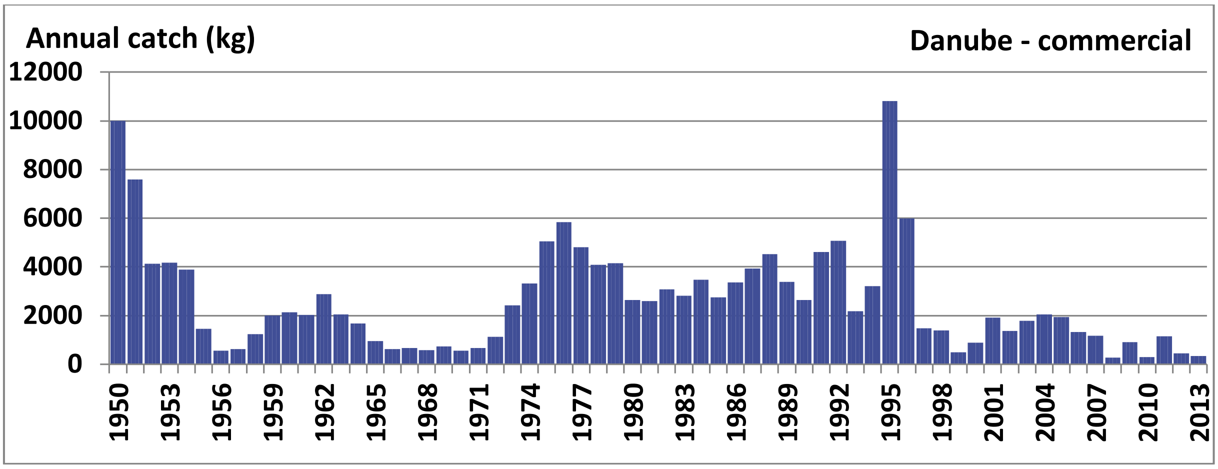

Figure 18: Commercial fishermen's annual sterlet catch in the Danube in the period between 1950 and 2013. (Tóth 1979, HALTERMOSZ database, OHA database)

The sterlet catches of Danube commercial fishermen can be traced since the early 1950s through various documents (Figure 18). Catch data from the first half of the 20th century are not known, but records from the time indicate that large quantities were caught in all parts of the Hungarian Danube until the 1930s. From the 1930s to the mid-1940s, sterlet abundance temporarily declined in the river section upstream of Budapest. In the second half of the 1940s, large shoals reappeared in the entire Hungarian river section (Tóth 1960). However, in the first half of the 1950s, the size of the stock rapidly declined both upstream and downstream of Budapest, with annual catches falling from 10,000 kg to nearly 500 kg in five years. Catches fluctuated around 1,200 kg until the early 1970s; then in the first half of the 1970s, a marked increase in catches began, approaching 6,000 kg. Until the mid-1990s, catches fluctuated around 3,000 kg. A remarkable catch of nearly 11,000 kg was recorded in 1995, but after that there was a very rapid decline, with catches falling below 500 kg within four years. This decline of more than 95% suggests that the sterlet population was overfished in 1995 and water pollution in 1998 may also have contributed to the decline of the populations (see chapter Extraordinary water pollutions). In the first half of the 2000s, catches increased to 2,000 kg, before falling back to the 300 kg level on several occasions, with a downward trend from the second half of the decade. The gradual reorganisation of traditional fisheries since the 1990s could also have had a significant impact on fish catches.

The fluctuations in the commercial sterlet catches in the Danube occasionally paralleled the catch data of anglers (Figure 19). An increase in catches in the 1970s, and a downward trend since the mid-2000s can be observed in both data sets. Based on similar trends, it is very likely that the Danube sterlet population increased significantly in the 1970s and then declined after the turn of the millennium. Since the early 1990s, however, there have been less correlated changes in the commercial and recreational data. The intensity of traditional fishing activities has presumably changed as a result of organisational restructuring. When the commercial fishermen removed a larger amount of sterlet from the population, it had a moderating effect on the anglers' catches. With the increase in the number of fishermen, their fishing intensity also changed during the given time period.

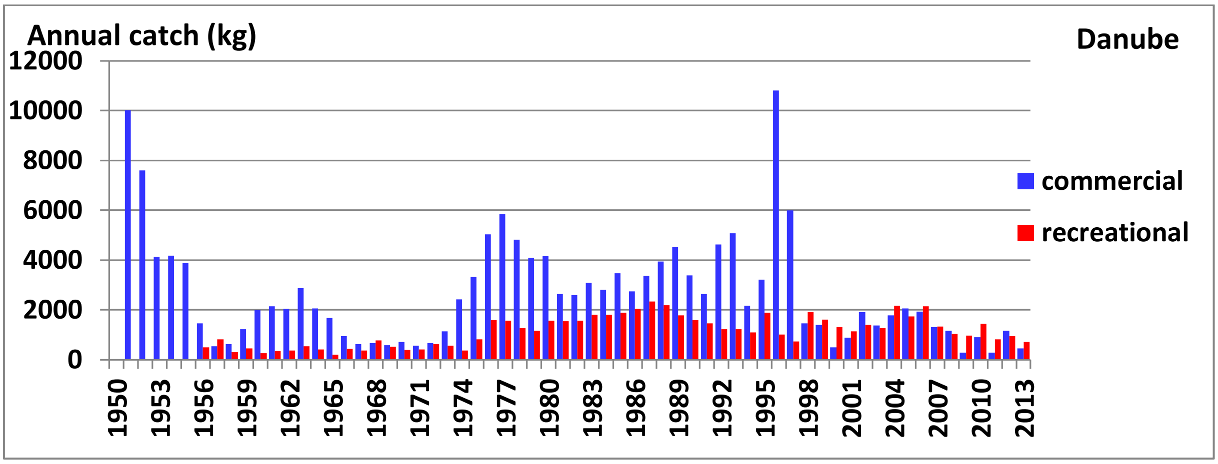

Figure 19: Annual sterlet catches of commercial and recreational fishermen in the Danube from 1950 to 2013 and 1956 to 2013.

There are different opinions in the literature regarding the observed increase in Danube populations in the 1970s. Some authors are of the opinion that the stocking of artificially propagated sterlet played a decisive role in the growth of the population at the time (Pintér 1989, Horváth et al. 1991, Ittzés et al. 2019). From the second half of the 1970s, the Warmwater Fish Hatchery in Százhalombatta and the Fishery Research Institute in Szarvas began to produce sterlet juveniles suitable for stocking in larger quantities, but at that time the lack of pituitary extracts from sturgeon species hampered large-scale production. Propagation technology started to improve significantly in 1986, with the use of synthetic hormones that replaced pituitary extracts. Sterlet stocking actions in the Danube were not systematic. According to incomplete data obtained from the documentation, 80,000 fry were stocked in 1988, 3,000 in 1991, 5,000 in 1992, 20,000 per year in 1996, 1999 and 2000, and 60,000 in 2002 in the Hungarian section of the Danube (Guti 2015).

Analysing the catch data of commercial fisheries, it can be concluded that the increase in Danube sterlet catches was already sixfold between 1970 and 1974, more than five years earlier than the start of sterlet breeding in the Warmwater Fish Hatchery. Therefore, the opinion of Ittzés et al. (2019), that sterlet catches started to increase due to the stocking actions in the early 1970s, is not substantiated. The significant increase in the catches and population can be explained primarily by environmental changes. During this period, the commissioning of the Iron

Gate I hydropower plant caused a significant hydraulic change along the lower section of the Middle Danube. The construction of the hydroelectric dam was completed in 1971. In the 135 km long reservoir created by the damming, 26 million tonnes of suspended sediment are deposited annually due to decreasing water flow (Teodoru and Wehrli 2005), which has adversely modified the habitat of the local sterlet population. Changes in fish catches in the Serbian (Yugoslav) Danube section clearly indicate that a significant proportion of the sterlet population has migrated upstream from the dammed river section. In the early 1970s, the abundance of sterlet in the reservoir area decreased significantly, while in the less dammed Smederovo section (30-40 km downstream of Belgrade), the abundance of sterlet in the commercial catches increased eightfold (Figure 20). In the following years, the sterlet catch increased in the Vojvodina and Hungarian sections of the Danube, so it is very likely that the rapid increase in catches indicates the spread of the populations migrating upstream from the lower section of the Middle Duna (Tóth 1979, Hensel and Holčik 1997).

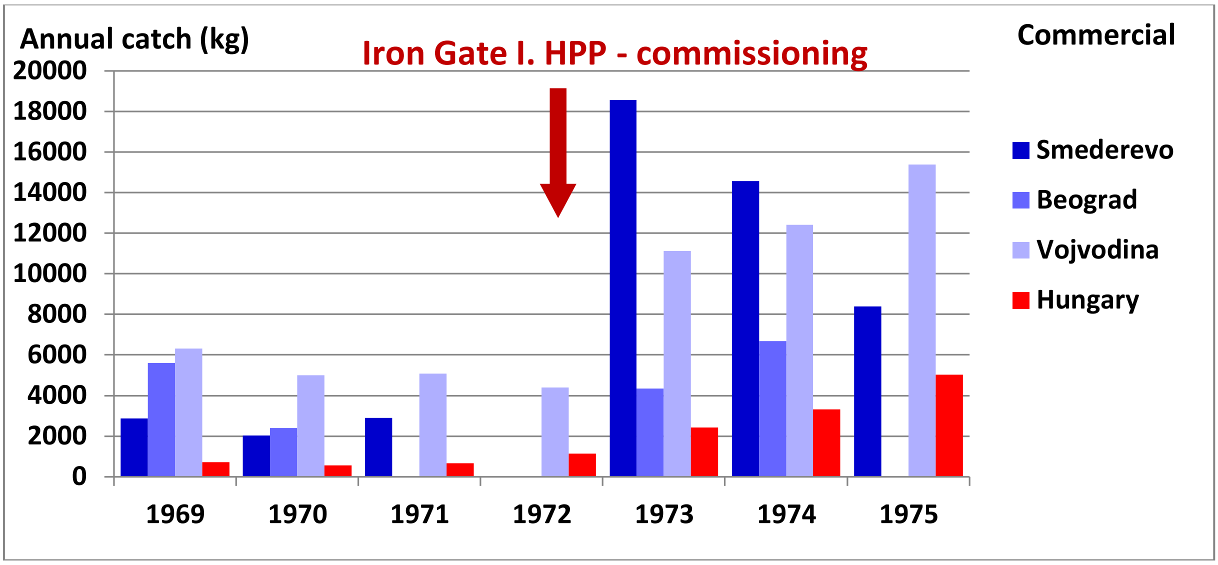

Figure 1: Annual sterlet catches of commercial fisheries on the Danube sections above the Iron Gate I reservoir from 1969-1975 (Catch data for the Serbian Danube section from Mirjana Lenhard).

In the 1970s, when the sterlet catch began to increase in the Hungarian section of the Danube, most sterlet were caught in the river section between Esztergom and Paks (Figure 21). Until the late 1960s, 70-90% of the sterlet catches were caught in the river section downstream of Paks. According to the catch frequency, a significant portion of the stock was concentrated in the middle section of the Danube and its upper region at the beginning of the 1970s. One reason for this may be the deterioration of the river water quality downstream of Budapest resulting from industrial developments that began in the 1950s. For example, a phenol concentration of 3 mg/l was measured 800 m below the sewage inflow of the Dunaújváros iron smelter in 1957 (Tóth 1960). Phenol pollution exceeding the limit values, as well as sewage from industrial areas, had an alarming effect on sterlet, and the appearance of larger sewage loads could also create periodic obstacles for fish moving upstream. The water quality adversely affected not only the sterlet, but also the barbel (which feeds on benthic organisms similar to the sterlet) whose population also decreased to a critical level during this period (Tóth 1960).

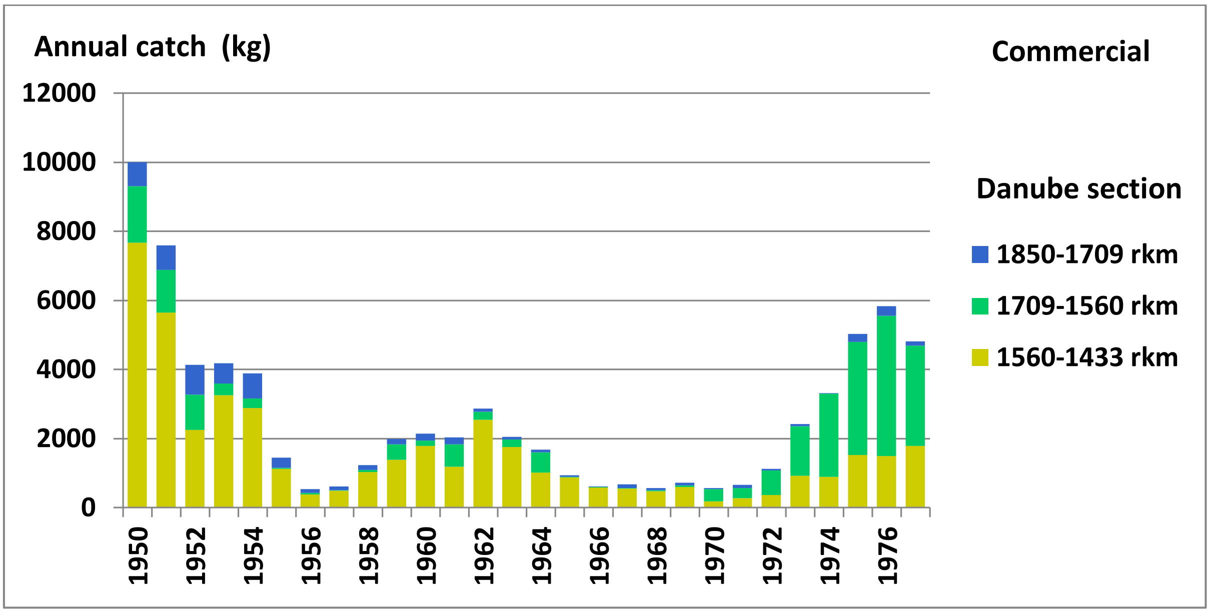

Figure 21: Quantitative distribution of commercial sterlet catches in the upper, middle and lower sections of of the Danube in Hungary between 1950 and 1977 (based on Tóth 1979).

By the beginning of the 21st century, the water quality of the Danube had improved significantly, but the commercial sterlet catch on the Danube has not reached the levels of the 1970s. When comparing catch numbers with previous years, it must be taken into account that the intensity of commercial fishing has decreased significantly since the 1990s, while angling has developed considerably. In the 2000s, the most sterlet caught from the Danube was in Pest county (Figure 22), with insignificant catches coming from Győr-Moson-Sopron and Komárom-Esztergom counties. In the river section between Komárom and Esztergom (1,770-1,720 rkm), traditional river fishing ceased in the 2000s. For example, in 2004, 82 kg of sterlet and 7 kg of barbel were caught (National Fishery Database). However, in Győr-Moson-Sopron county (1,850-1,770 rkm), commercial fishing was still intensive during the same period and while 11,000 kg of barbel were caught, only 5 kg of sterlet were found (National Fishery Database). Therefore, the negligible sterlet catch reflects a decrease in the local population.

Until 1992 in Győr-Moson-Sopron counties, the main sterlet fishing ground was the Szigetköz section of the Danube (1850-1794 rkm). The trends in the catch data recorded since the 1950s (Figure 23) are similar to those in the other sections of the river until the time of the commissioning of the Gabčikovo river barrage system (1992), when the sterlet catch decreased by two orders of magnitude in one year and remained at an insignificant level thereafter. The operation of the Gabčikovo hydropower plant fundamentally changed the water supply of the extensive floodplain sidearm system. Almost 80% of the Danube's flow has been diverted to the hydropower plant's canal, bypassing the sidearm system for 40 km. In the 1980s, sterlet were mostly caught in the 4 km section of the Bagaméri sidearm (1810 rkm) in the lower area of the Szigetköz floodplain, during the spring and early summer. This area could have been the spawning ground of the local sterlet population. The decrease in the water supply of the sidearm led to an intensive siltation process since 1992, as a result of which 346,000 m^3 of fine-grained silt (a layer almost 60 cm thick) was deposited between 1993 and 2005 (Rákóczi and Sass 2005) in the former spawning substrate of the sterlet. Changes in the spawning substrate act as a barrier to sturgeon reproduction (Rochard et al. 1990, Reinartz 2002), so it is likely that the rapid disappearance of the sterlet in the Szigetköz section of the Danube is due to siltation in the former spawning habitat.

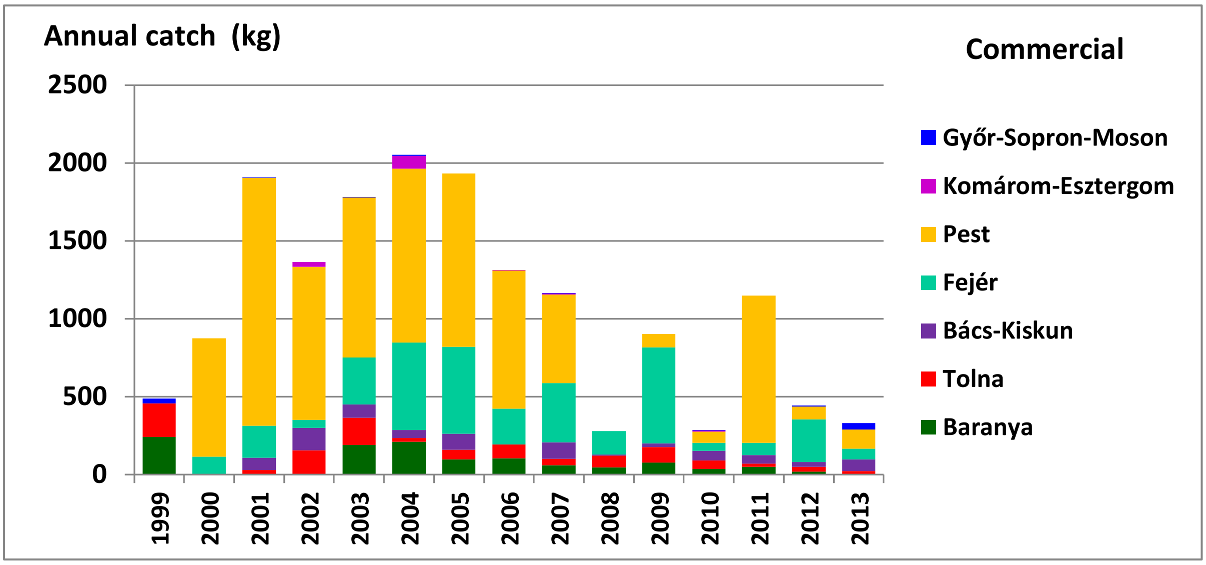

Figure 22: Quantitative distribution of commercial sterlet catches by county along the Hungarian section of the Danube between 1999 and 2013 (based on OHA database).

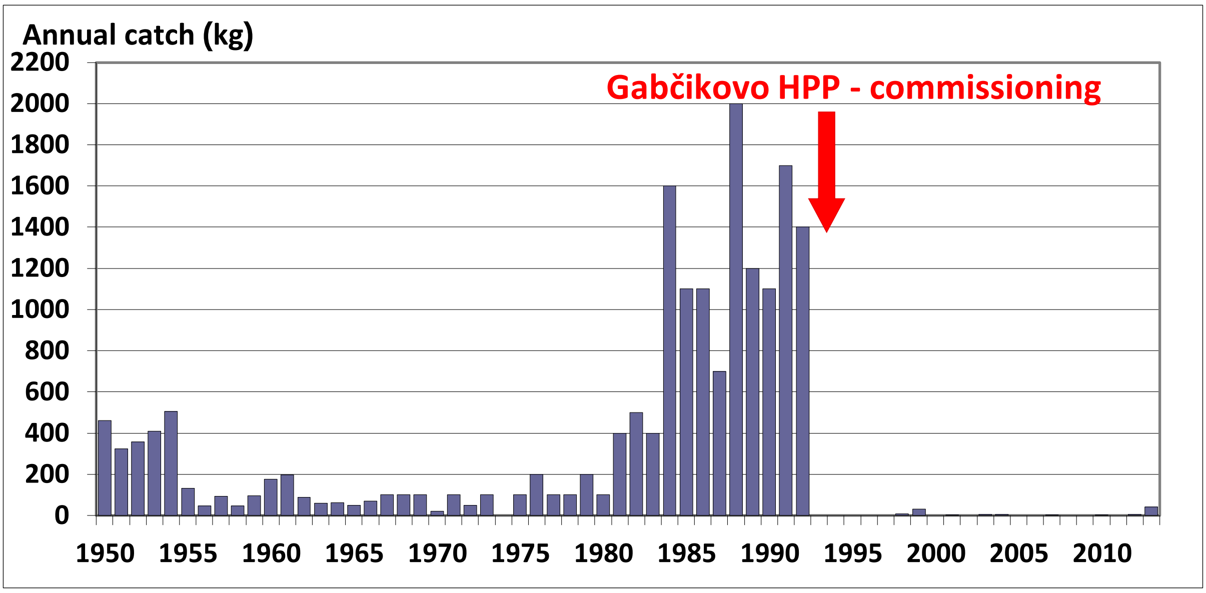

Figure 23: The commercial sterlet catch in the Szigetköz section of the Danube between 1950 and 2013 (Based on Jancsó and Tóth 1987, Guti 2006 and OHA database).

Utilisation and conservation status

The importance of sterlet fishing in the Danube and its tributaries has been paramount in recent centuries. Sterlet have tolerated human pressures and environmental changes better than other sturgeon species and they were caught in significant quantities by commercial fishermen (average catch 10.7 t/year between 1950 and 2000) and anglers (average catch 5.5 t/year between 1950 and 2000) in the major rivers of Hungary until the beginning of the 21st century.

Large-scale plans to develop fisheries in natural waters, developed in the 1970s, have not been implemented; subsequently, commercial fishing did not find a way to survive alongside the rapid development of angling. In the 1990s, the fisheries directorate was weakened and, thereafter, the trend towards the elimination of commercial fishing was observed, alongside the gradual expansion of recreational fishing (Pintér 1995). The change in attitude to natural water fisheries management is reflected in Act CII of 2013 on Fisheries Management and Fish Conservation, which abolished commercial fishing in the natural waters of Hungary. Decree 133/2013 (29.XII.) of the Ministry of Rural Development classified the sterlet among the "non-catchable" fish species from 2014, making it impossible to exploit sterlet caught in natural waters in Hungary. It can only be fished with a special, occasional fishing permit issued by the fisheries authority. Consumer demand is currently met by the production of aquaculture-reared sterlet. The annual production volume of edible sterlet is around 10-15 tonnes in Hungary (verbal information from Á. Rideg).

The sterlet is currently not classified as a protected species in Hungary, but it is listed as a threatened species on the IUCN (World Conservation Union) international red list (http://www.iucnredlist.org). According to the IUCN endangered status, the sterlet population has decreased significantly since the 19th century, and the probability of extinction in wild populations is high.

Since 1974, native fish species of outstanding natural value have been protected in Hungary. The sterlet was classified as a protected species from 1974 to 1982, but despite its protection, it was continuously caught by commercial fisheries and anglers at an average annual catch of 12 tonnes (about 23,000 specimens/year). After the termination of the protected status of sterlet, its exploitation was regulated by a closed season (1.1.-31.5.2007), a size limit (40 cm) and a catch quota (3 fish/day). The size limit was changed to 45 cm in 1998. Despite the restrictive measures and the repeated stocking of juveniles, a downward trend in catch data has been observed since the late 1990s. The above-mentioned Decree 133/2013 (29.XII.) aims to stop these trends in catch data by classifying the sterlet as a "non-catchable" fish species.

The protection of sterlet is also regulated by a number of international conventions. These include the 1979 *Convention on the Conservation of Migratory Species of Wild Animals* (Bonn Convention), which was established under the auspices of the United Nations Environment Programme (UNEP) to promote the coordinated international conservation of and research on migratory species. Hungary acceded to the Convention in 1983. Under the Convention, in order to prevent the extinction of the endangered species and species with an unfavorable conservation status listed in its annexes, important habitats must be protected or restored where able, and the adverse effects of activities and obstacles which significantly hinder the migration of species must be prevented or compensated for and minimized in the appropriate way. The legal protection of the species covered by the Convention is ensured by *Act LIII of 1996 on the Protection of Nature* and by *Decree 13/2001 of the Ministry of Environment Protection on the protected and strictly protected species of plants and animals, the strictly protected caves and the publication of the species of flora and fauna of conservation importance in the European Community*. (Sterlet is listed in Annex II to the Convention).

Another important international agreement concerning the sterlet is the *Convention on the Conservation of European Wildlife and Natural Habitats* (Bern Convention), established in 1979 within the framework of the European Economic Community, which has the basic objective of promoting cooperation between the signatory countries for the conservation of wild plants and animals and their natural habitats, as well as endangered migratory species. Hungary acceded to the Convention in 1989. The Convention states that wild fauna and flora constitute an extremely valuable natural heritage that must be preserved and passed on to future generations. The Convention encourages and provides a technical basis for the reintroduction of European species on the brink of extinction, and includes provisions for the control of alien species and their introduction. Annexes to the Convention identify protected and specially protected plant and animal species (the sterlet is listed in Annex III to the Bern Convention).

The Bern Convention was first implemented by *Council Directive 79/409/EEC* (Birds Directive) and later by *Council Directive 92/43/EEC* (Habitats Directive). The two Directives form the two main pillars of EU nature conservation legislation, which together form the Natura 2000 network. Natura 2000 is a coherent European network that ensures the conservation of biodiversity through the protection of natural habitats and wild fauna and flora. The aim of the network sites is not to protect them as reserves, but to ensure the conservation and maintenance of natural values through human activities, management and the integration of nature conservation, economic, social and cultural interests. (The sterlet is listed in Appendix V of the Habitat Protection Directive.)

An important international agreement for the export of farmed sterlet is the *Washington Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES), signed in 1973 to ensure that international trade in wild plants and animals do not endanger the survival of natural populations. Hungary signed the Convention in 1985. (The sterlet is listed in Annex II of the Convention.)

Pressures on sterlet populations

Over the past century of human history, river ecosystems have been the most heavily modified by anthropogenic pressures on a global scale, with negative consequences including changes in the biodiversity of fish stocks (WWF 2020). The starting point for effective conservation of sterlet populations is to identify the causal links between human activities and environmental changes in river ecosystems and to understand their interdependent, cumulative effects.

The decline of the Hungarian sterlet population is evident from the downward trend in the catches of commercial and recreational fisheries since the end of the 20th century. However, in the available data series of more than six decades, there was already a period of decline, after which the stock has recovered. This decline can be explained by a number of negative processes and impacts, some of which limit abundance and recruitment of populations by indirectly altering vital habitats and others by directly stressing individuals by reducing their survival. Anthropogenic pressures on sterlet populations are less species-specific and have negative impacts on other elements of the native fish fauna.

The abundance of fish stocks in the natural waters of the Carpathian Basin declined in the second half of the 19th century to the point where they became a problem for feeding the human population. In 1865, the Hungarian Governor's Council turned to the Natural Science Society to find out the causes of the fish depletion. Kriesch (1868) summarised the main sources of threats in a committee set up to investigate the issue:

- deforestation → streams and drainages dry up → spawning grounds are destroyed
- river regulation → drying up of floodplain waters → the loss of fish-rearing habitats
- overfishing → excessive fishing even during spawning periods
- construction of sluices and dams in river beds → restricting fish migration
- industrial water pollution → poisoning of fish and other organisms
- steamboating → waves damage the eggs and juvenile fish
- timber drifting along rivers → piling up of wood destroys spawning areas
- damage to fish-eating animals (gulls, herons, grasshoppers, cormorants, otters, etc.)

Some of the problems described one and a half centuries ago still persist today, and by the beginning of the 21st century, the vulnerability of native riverine fish populations has increased. Nowadays, as a result of water and land use, the larger rivers have already been heavily modified and have lost their natural character. Adverse changes in river fish habitats have reduced the production and natural recruitment of many native fish species. In addition to the direct pressures associated with economic activity, further problems are expected as a result of changing climatic conditions in the Danube basin.

River regulations

Damming

Damming facilities built along the river bed and crossing the flow direction satisfy several social and economic needs, they can serve as flood protection, water storage, hydropower utilization, water extraction for irrigation purposes, etc. Hydropower plants are often promoted as a means of economic development (World Commission on Dams 2000), providing a beneficial and long-term investment in the water and energy sectors. Other experts (Winemiller et al. 2016), however, express concern that the economic benefits of hydropower utilization are overestimated, as economic forecasts often exclude or underestimate the loss of ecosystem services, the costs of mitigating associated environmental risks, and the costs of ensuring the long-term maintenance of hydropower plants.

Due to the threats to river ecosystems and their wildlife, there is an increasing need for the sustainable and integrated management of rivers worldwide. Longitudinal migration along the river between different habitats is essential for the normal life history and successful reproduction of most river fish species, without which, fragmentation of the migration routes leads to the local disappearance of certain species. Interruption of the passability of river water systems has played a decisive role in the global decline of more than 80% of freshwater fish species since the 1970s (WWF 2020). In the water system of the Danube, the construction of dams and barrages is one of the main environmental pressures. Along the entire river system, 747 barriers have been identified that limit fish migration (National Administration Romanian Waters 2018).

On the Hungarian section of the Danube and its major tributaries, as well as on the Hungarian section of the Tisza and its major tributaries, there are 12 to 12 larger dams. (Danube: Dunakiliti; Moson Danube: Vének, Mosonmagyóvár; Rába: Alsószölnök, Szentgotthárd, Magyarlak, Csörötnek, Körmend, Ikervár, Nick; Ipel: Ipolytölgyes, Tésa) (Tisza: Tiszalök, Kisköre; Hernád: Gibárt, Felsődobsza, Kesznyéten; Túr: estuary fall; Körös: Körösladány, Gyula, Békés, Békésszentandrás, Bökeny; Hortobágy-Berettyó: estuary fall). At several dams these rivers, where a fish ladder provides a link from the lower to the upper reaches, the ecological corridor function has not or has only partially been properly achieved, in recent decades.

Migration between spatially extensive and temporally variable habitats plays a fundamental role in the life history of the sterlet, which is dependent on the functional connectivity of the diverse habitats of the river system. Migration allows access to: river sections rich in food organisms, the most suitable habitats for spawning, and sheltered areas of the riverbed for surviving the cold winter periods and extreme water conditions.

Where transverse flow control structures prevent spawning migration of sterlet, spawning does not occur or may take place in less suitable river sections and the habitat characteristics of the riverbed may be insufficient for embryos and larvae drifting downstream from the spawning site. Dams modify the flow conditions and the sediment transport of the river. The sediment deposition, higher water temperatures and lower oxygen levels in dammed river sections are intolerable to sterlet and limit their reproductive potential (Rochard et al. 1990, Reinartz 2002).

At the same time, in the river sections downstream of the dams, changes in hydraulic conditions, rearrangement of the bed material, or changes in the distribution of the most important food source organisms can limit the extent of usable habitats for the sterlet.

Channelization

The hydrodynamic processes shaping the Danube's morphology have been strongly modified as a result of centuries-old, small- and medium-scale river regulations that improve the river's navigability. Until the second half of the 19th century, before comprehensive regulations, navigation along the Danube was limited by permanent changes in the riverbed and the formation of gravel bars. Navigation difficulties were mitigated by: the cutting of specific meanders, paving of the river bank to the mid-water level along instable sections, and closing the upper mouths of several river branches to prevent water spreading at low river levels.

The river engineering has resulted in an increase in the flow velocity and sediment transport capacity of the Danube, which has led to the incision of the river bed. This process resulted in a decreasing trend of low water levels along several river sections. With the gradual deepening of the main channel, the water supply to the side branches and the frequency and duration of inundation in the floodplains has decreased. As a result of modified erosion processes in the upper watershed, larger floods transport a significant amount of suspended sediment, most of which is deposited in the floodplains between flood protection dikes, forming alluvial plugs in the mouths of the side branches and natural levees along the river. With the continuous rise of the floodplain's elevation due to the accumulation of sediment, the frequency of side branch flushing and floodplain inundations has further declined. With the gradual silting up of the side branches, a direct connection between the main channel and the side branches becomes less and less frequent and the spatial and temporal extent of the floodplain water bodies are reduced.

In the process of straightening the riverbed for improved navigability, the longitudinal gradient of the bed increases; therefore, the bed shear stress, which moves the particles of bed material, increases during high flows. A significant increase in the bed shear stress reduces the probability of survival of the eggs attached to the gravel substrate and the drifting fish larvae, which has a negative impact on the breeding success of the sterlet spawning on the gravel substrate. Additionally, in the once gravel-bottomed side arms, as flow becomes more restricted, the layer of silt formed by the deposition of suspended sediment also limits the reproductive success of fish species that spawn on the gravel bed. This process was observed in the Szigetköz section of the Danube after the commissioning of the Gabcikovo hydropower plant, which led to a rapid decline in sterlet catches (Figure 23).

The dredging of the fords is used to quickly and temporarily improve the depth conditions of the waterway, the route of which is determined by taking into account the flow conditions. The dredging alters the geometry of the river section and may result in lower discharge levels. Where the intervention removes the armoured surface gravel layer of the bed, extensive bed erosion and progressive bed incision may develop. Altered hydraulic conditions resulting from dredging may damage the spawning grounds for sterlet. Part of the dredged sediment drifts as suspended sediment and is deposited in a more distant river section. The deposition of sediment threatens the reproductive success of the sterlet and increases the mortality of juveniles during their early developmental period. Noise from dredging machines increases the production of the hormone cortisol in fish, which can adversely affect their spawning (Wysocki et al. 2006). The bed material excavated during dredging is often placed in the deeper sections of the river, which also endangers the sterlet's habitats, especially their winter shelters.

Navigation

According to the Danube shipping traffic forecast, the number of freight vessels (currently 7,857 vessels/year) on the Hungarian section of the river is expected to increase by 34% (10,505 vessels/year) by 2040. The planned waterway improvements will also result in an increase in the annual length of the navigation period, from the current 240 days to around 340 days. The number of cargo vessels is expected to remain relatively constant throughout the year, ranging from 800 to 1,100 vessels/month (Guti 2020), without significant seasonal fluctuations. Passenger traffic is also expected to increase, with the number of vessels increasing by about 50% (54 vessels/day) by 2040 and 75% (63 vessels/day) by 2050. The majority of passenger boats will operate in and around Budapest (excursion boats, event boats). The seasonal variation in passenger boat traffic is significant, with a large part of the traffic taking place between April and October (Guti 2020).

Waves crashing on shore

Among the adverse impacts of increasing ship traffic, the strong waves that accompany the ships are well known, which can damage the most productive habitat of the river, the aquatic-terrestrial transition zone, and indirectly reduce the river's self-purification ability. Repeated waves due to regular boat traffic usually do not lead to spectacular fish mortality, but the persistence of waves is a continuous stress factor that can significantly reduce the abundance of various fish species.

The sterlet is a benthic species and its juveniles live on the bottom of deeper sections of the bed, so it is less likely that wave actions would directly disturb their habitat. The macroinvertebrate organisms that form the sterlet diet mostly inhabit the bottom of the medial zone of the river bed, so they are not directly affected by the waves crashing along the shoreline either. In periods of particularly low water levels, it is possible that strong water movement accompanying larger ships may sweep away individuals in the early stages of development, adversely affecting their resilience.

Noise load

Ships traveling on the Danube are usually powered by diesel engines, whose power can be increased by the number of cylinders. Increasing the number of cylinders also means lengthening the crankshaft, which flexes and vibrates. This vibration spreads through the entire ship's structure, propagating through the engine base. The mechanical vibration and strong noise of the engine, propeller and hull spreading through the water is detrimental to fish. It is well known that fish try to avoid larger vessels approaching them. Studies on the Austrian stretch of the Danube have shown that so-called "noise pollution" from ships increases the production of cortisol, known as a stress related hormone, by 80-120% in fish (carp, gudgeon, perch) compared to fish in a noise-free situation. The relatively acute stress response is independent of the different auditory abilities of fish species. Regularly elevated cortisol levels can have detrimental effects on fish growth, reproductive development and reproduction (Wysocki et al. 2006). The effect of noise stress on sterlet is not known.

Water pollution from ships

Sometimes leaking fuel and lubricants from ships can enter the water. When cleaning the ship's hull and its cargo space, pollutants can enter the river with the removed bilge water. Ship waste, wire rope, parts, etc. are regularly found in the river bed along the waterway and around the ports. In addition, unpredictable and extraordinary water pollution can occur in the event of shipping accidents, when hazardous substances from the cargo are discharged into the water.

The release of hazardous substances from ships into the water may have adverse effects on the growth, development and reproduction of sterlet and on the abundance of organisms that make up their food.

Emissions of pollutants

Diffuse water pollution

Regarding diffuse pollution, pollutants enter the water over a larger spatial extent, primarily as a result of heavy rains. The dynamics of diffuse water pollution is related to the seasonality of the weather, so it is much more variable in time and space than point sources of pollution. The most widespread diffuse pollution of surface waters is caused by the washing of agricultural organic matter, plant nutrients and pesticides (herbicides, fungicides, insecticides, etc.). In the case of organic material loading (humus, plant debris, agricultural waste, etc.), the dissolved oxygen content of the water may decrease to a greater extent on warm, windless summer days as a result of the decomposition process. Species that are sensitive to the lack of dissolved oxygen, such as the sterlet, will escape from or even die in stressed water bodies.

Point source water pollution

In point source pollution, the pollutant is concentrated in space through something such as a pipeline or open channel. Point source pollution is mostly caused by discharges from wastewater treatment plants, storm water reservoirs and industrial facilities in the vicinity of larger agglomerations. In Budapest, for example, 300,000 m^3/s of untreated wastewater per day was discharged into the Danube before the central sewage treatment plant was commissioned in 2010. The use of modern wastewater treatment technology is not always a complete solution.

Fish are particularly sensitive to severe water pollution, ranging from individual histological lesions to changes in the entire population. The accumulation of heavy metals and other pollutants in river sediments usually threatens fish species that feed on benthic organisms. Surveys in the Serbian section of the Danube have shown that the frequency of sublethal histopathological lesions in the gills, skin and liver of sterlet is associated with increasing concentrations of heavy metals and anthracene in sediments (Lenhardt et al. 2004, Jarić et al. 2011). The accumulation of heavy metals and trace elements in the Danube sterlet was analysed in fish samples collected from the Serbian section of the river (Palánka, Belgrade) in 2006 (Jarić et al. 2011). In total, the distribution of 18 metals (Ag, Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sr, Zn, Li) was detected in the muscle tissue, liver, gills and intestines of the fish. The analysis showed the highest accumulations were in the liver and the lowest accumulations were in the muscle tissue. The heavy metal content in muscle tissue was below the limit value for human consumption (European Commission Regulation 1881/2006/EC) for all metals, except for cadmium. Cadmium was 70% above the limit value in the muscle tissue and 560% above the limit value in the liver. Cadmium is a dangerous heavy metal, as it is difficult to excrete from the human body (it has a half-life of 30 years) and can cause serious acute damage, including stomach and intestinal disorders, as well as long-term damage to the kidneys and bones, and it is a probable carcinogen.This study draws attention to the need for a more effective control of contaminants in fish products from natural waters and it also highlights the problem with the absence of officially defined limit values for many metals in European legislation.

Accidental water pollution

Accidental water pollution events occur unexpectedly, at unpredictable times and relatively quickly, usually as a result of hazardous substances being released during industrial accidents, which can partially or completely destroy fish stocks and fish food webs.

One of the most serious incidents in recent history in Hungary occurred in 1998, when a technical malfunction resulted in a large spill of pesticides into the Danube. A chemical factory near Nagytétény (1630 rkm) spilled 120 litres of an insecticide called Chinmix (containing 50 g/l of the active substance beta-cypermethrin) into the river. Water samples taken at Dunaföldvár, 70 km downstream from the source of the pollution, contained 2.7-3.5 µg/l of cypermethrin. This concentration is lethal for crabs and fish (LC50 values are 0.9 µg/l for pike, 2.7 µg/l for carp and 0.26 µg/l for crayfish). As a result, fish died in large numbers along a stretch of the Danube in the hours immediately following the accidental spill (Pénzes 1998).

Another noteworthy event was the flooding of the sludge storage pond at the Baia Mare (Nagybánya) gold mine in 2000, which resulted in almost 100,000 m^3 of cyanide-containing wastewater being discharged into the Tisza via the Szamos River. The "cyanide tsunami" on the Hungarian stretch of the river caused considerable and direct damage to the river fauna. A few weeks later, in the Baia Borșa (Borsabánya) area, a similar incident resulted in a high concentration of sludge water contaminated with heavy metal salts flowing into the Tisza via the Viso River. Some of the toxic sludge settled out on the river's floodplains, but the heavy metals from the sediment that entered the food web continued to pollute the aquatic organisms for a longer period.

Another well-known environmental disaster that has claimed human lives is the so-called Ajka red sludge disaster. In October 2010, the dam at the red sludge storage facility of the Ajka alumina factory between Kolontár and Ajka burst, spilling more than 1,000,000 m^3 of highly alkaline, corrosive sludge that flooded a significant part of the surrounding settlements. The pollutant was transported via the Marcal to the Rába, and from there to the Moson Danube and the Danube. Looking at the internet posts of anglers at the time, dead fish were found along the banks of the Danube as far away as Budapest in the following days (Figure 24). The reports were mainly about dead individuals of benthic river species such as barbel, vimba bream and sterlet (Szily 2010).

Figure 24: Dead benthic river fish from the Danube at Budapest in the days following the Ajka red sludge disaster (vimba bream and sterlet).

Environmental pollution caused by plastics

Environmental pollution from plastics is increasing worldwide. As a result of inappropriate waste management technologies, plastics released into the environment remain in natural habitats for a long time, with their gradual decomposition taking decades or even centuries. During decomposition, the polymer chains that make up the plastics break down, but their biodegradation is a very slow process due, in part, to the molecular weight of the resulting fragments usually exceeding the usable size for microorganisms. As a result of this and the continous production and use of plastics, the amount of plastics is accumulating in the environment, leading to serious environmental problems. Plastic waste drifting through river systems contributed around 80% to the 270 million tons of plastic accumulated in the seas and oceans by the 2010s (Eriksen et al. 2014). For example, on the Austrian section of the Danube, more than 1,500 tons of plastic debris less than 5 cm in size drifts towards the Black Sea every year (Lechner et al. 2014).

Microplastics (plastic particles smaller than 5 mm) are considered one of the main problems of plastic pollution. A significant proportion of microplastics come from the waste released into the environment, which is fragmented as a result of mechanical, chemical, physical and biological processes. In surface waters, depending on their density, microplastics can float on the surface of the water or settle to the bottom. Depending on their spatial distribution, they can affect different aquatic species such as planktonic organisms, macroinvertebrates (particularly molluscs and crustaceans) and fish.

Microplastics pose a significant risk to aquatic organisms. Ingested plastic particles, depending on their size and roughness, can cause physical damage to the surface of the fish's alimentary canal, embed themselves in connective tissues and, in larger quantities, they can cause blockage of the digestive organs (Wright et al. 2013). They can also reduce fish feeding activity and limit the absorption of nutrients.

Plastic particles smaller than 1 µm can pass through the cell membrane and are detectable in the blood of most people. The microplastics that enter organisms can release toxic additives used in their production, which can affect the functioning of an organisms endocrine system and the production of estrogenic hormones, thus affecting their reproductive function (Bordós and Reiber 2016). Microplastics with a high specific surface area, low polarity and hydrophobic properties have been shown to absorb dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), bisphenol A (BPA), polyfluoroalkyl substances (PFAS), antibiotics and heavy metals. These substances also affect the endocrine and reproductive systems, as well as the immune and nervous systems (Vo and Pham 2021).

There are no concrete observations on the threat level and damage to fish stocks from the presence and accumulation of different plastic compounds in food webs in the natural waters of Hungary. The risks to food safety and human health from the consumption of fish contaminated with microplastics are not well understood, so clarifying the cumulative toxic expression of microplastics in environments polluted to varying degrees is a challenging research task.

Control of mosquito populations

Under the Hungarian mosquito control programme, a total of 7,700 km^2 are treated annually using chemical methods (Figure 25) to account for the emergence of biting mosquitoes from April to September, while a less environmentally damaging biological method is used on a maximum of 300 km^2. Biological mosquito control involves the introduction of an active substance produced by a bacterium into water bodies where mosquito larvae are developing. The advantage of this method is that only the larvae of biting mosquitoes are killed and the risk to other animals from the biological agent is negligible.

With chemical mosquito control, a pyrethroid active substance (deltamethrin, lambda-cyhalothrin) that affects the insects' nervous system is sprayed into the air to kill adult mosquitoes. Spraying can be done from aircraft or ground vehicles. One option for aerial application is the so-called ULV (ultra low volume: 0.5-0.8 litres per hectare) fine-drop method, where an active ingredient dissolved in water is sprayed in solution. ULV nozzles are used to produce very fine spray droplets (90% of which are 50-60 µm in diameter) that settle slowly to the ground level over a period of hours. The spray, which descends from the top down, comes into contact primarily with flying insects. The method is ineffective on non-flying mosquitoes hiding on the underside of leaves, so the water-based ULV method is most effective at sunset or dawn when mosquito activity is higher. Spraying from a vehicle is also feasible, but if done from an aircraft, a larger area can be treated in a much shorter time.

Another common method of killing adult mosquitoes is the so-called warm mist method, whereby the pyrethroid active ingredient is sprayed into the air in a paraffin-based, white oil solution heated to 500-600°C. The process, which uses a vehicle-mounted hot mist generator, sprays droplets of less than 20 µm in diameter into the air. The spray spreads horizontally as a milky white toxic mist, floating for up to 40-60 minutes, and is effective in killing non-flying and vegetation-hiding insects.

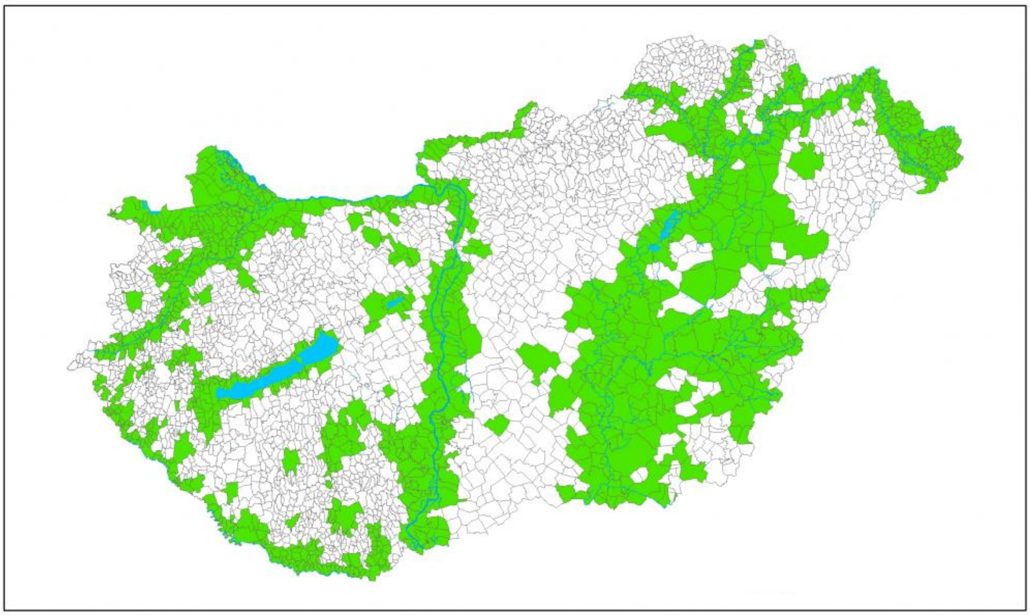

Figure 25: Areas treated with chemical agents (green) during the mosquito control programme in 2020 (Source: BM OKF)

Surveys on the results of warm mist control have shown that the proportion of biting mosquitoes, representing the target group among the dead insects, was only 0.1% (Fekete et al. 2006), so the method should be considered as non-selective for mosquitoes. The general threat to natural insect populations is indicated by a 27-year survey series in 63 nature reserves in Germany, which studied the status of local insect fauna. Analyses showed a seasonal decline of 76% in flying insect biomass over the 27-year period, with an 82% decline in mid-summer (Hallmann et al. 2017). The decline in insect populations due to chemical treatments for mosquito control can explain, among other things, the decline of the barn swallow population by about 50% in Hungary between 1999 and 2013. Following mosquito control, the number of dead birds usually increases (Hungarian Ornithological and Nature Conservation Society 2021a).

Pyrethroid active substances released into the air or on the surface of the water are rapidly degraded by light. The degradation time in running water is less than five days, but the biological activity can persist for longer periods in insects. Pyrethroid active substances are not considered to be insect-selective, are highly toxic to some aquatic organisms and may accumulate in fish and molluscs. They are especially toxic to fish (fish LC50: 0.91-1.4 µg/l) (Polgár et al. 2006).

In Hungary, mosquito control practices lack effective measures to avoid pressures on the riparian zone of surface waters. The pyrethroid active substances are classified as specifically hazardous to aquatic organisms, therefore in plant protection practice, it is forbidden to use it within 5-50 m of the surface water. Conversely, if the pyrethroid-containing product is used as an exterminant, it is sufficient to keep a 5 m safety zone from the banks of watercourses. (Havasréti 2018). In the early 2020s, it was observed in riverside settlements that when chemical mosquito control was carried out on the riverside, the spray drifted over the Natura 2000 sites. Mosquito control was carried out more than once during the mass swarming period of protected aquatic insects (e.g. Danube mayfly - *Ephoron virgo*), which are an important food source for the sterlet.

In aerial spraying with ULV fine droplet technology, small spray droplets can drift thousands of metres away from the intended target area, even in a light air current (<10 km/h wind speed). According to the provisions of the Joint Decree 44/2005 FVM-KGM-KvVM on aerial work in agriculture and forestry, ULV technology has not been used in field since 2008. However, it is still used for chemical mosquito control in Hungary.

Products containing pyrethroids sprayed near rivers pose less of a direct threat to sterlet populations in deeper areas of the riverbed. However, insecticides have a direct impact on arthropods, including the important fish food sources like chironomids, mayflies, crustaceans, etc.; indirectly affecting all insectivorous species and, thus, practically affecting the entire food web. The impact of mosquito control programs on sterlet and other fish species is poorly understood in Hungary. However, the declining trends in fish catches are likely related to the significant reduction in aquatic insect biomass through the widespread use of chemical mosquito controls in recent decades. From a fisheries and conservation point of view, the mass killing of important fish food organisms is unacceptable.

Fisheries management for angling purposes

Prior fishing exploitation of the Hungarian sterlet stock affected the dynamics of the wild populations by removing a significant amount of fish. From the early 2000s to 2013, the sterlet catch of commercial fisheries fell from 7.6 tonnes to 2.2 tonnes, and that of anglers from 4.5 tonnes to 3.3 tonnes. This decline was observed on all major rivers. The downward trend in catches indicates a decline in population size. When assessing the sustainability of angling practices, an important question is how the loss resulting from the removal of individuals of the population by fishing is added to the other negative effects that can also reduce the population. The population usually compensates for the total loss (natural mortality + fishing mortality + mortality from anthropogenic pressures).

The basis for sustainable fishery management is avoiding the decline of fish populations by limiting angling activities to below the maximum yield level. The level of yield can be estimated from factors of population dynamics (stock size, growth of individuals, age distribution, condition, etc.). In Hungary, managers of fisheries do not have the necessary information to plan for the sustainable exploitation of sterlet populations. Due to methodological limitations, the Hungarian fish biology monitoring programmes (WFD and NBmS) are not suitable for assessing the sterlet populations living in the deeper areas of the riverbed, and a monitoring system for the survey of sturgeons is not in place either, unlike in many other Danube countries. In the absence of adequate monitoring programs, it is difficult to evaluate the long-term changes in sterlet populations and the results of stocking actions that are intended to increase their numbers.

Decree 133/2013 (29.XII.) of the Hungarian Ministry of Rural Development established certain rules for fish management and fish protection, including listing sterlet among the "non-catchable" species beginning in 2014. Therefore, anglers are obliged to release all caught individuals. This measure is not popular among anglers and many would like to see its withdrawal. As such, the Hungarian Anglers' Association launched a programme in 2021 to assess sterlet stocks with the aim of returning sterlet from "non-catchable" to "catchable" status in Hungary by 2025. The action, which is planned to run for three years, provides support for the stocking of around 8,000 sterlet each year that are longer than 30 cm and have a numbered mark. The campaign is being promoted under the slogan, "Let sterlet become an angling Hungaricum".

Figure 26: Release of artificially propagated one-year-old sterlet into the Danube (Photo: G. Guti)

Fishery organisations have been stocking sterlet on the Hungarian stretches of the Danube, Tisza and their major tributaries for decades, with the aim of increasing sterlet populations. Unlike previous actions, the current practice is to release larger one- or two-year old fish rather than larvae or juveniles that are a few cm long. Several Hungarian fish farms are engaged in the breeding and rearing of sterlet, ensuring the production of juveniles in the quantity necessary to increase the natural populations. Knowledge on the effectiveness of fish stocking in Hungary is rather limited, and monitoring of the behaviour, survival and migration of introduced specimens is therefore strongly recommended.

There is a lack of knowledge on the occurrence of reproductive polymorphisms in Hungarian sterlet populations that facilitate their adaptation to locally variable habitat conditions. For many sturgeon species, several sub-populations are known to occur within a given river section, forming a so-called metapopulation. Sub-populations are distinct in terms of their spawning grounds or migratory behaviour (Bayley and Li 1996). Metapopulations are generally characterised by polymorphic reproductive behaviour, which can be beneficial in adapting to stochastic variability in riverine environments. The annual variation in river flow tends to favour the reproduction of different subpopulations, so that the expansion and retreat of individual subpopulations compensate each other in the long term. Reproductive polymorphisms allow for fine adaptations to locally variable habitat conditions or to larger-scale environmental gradients. According to some authors (Currens et al. 1990), reproductive polymorphisms are genetically controlled.

In the fluvial system of the Danube, the occurrence of a metapopulation of sterlet is assumed, but our knowledge about this is incomplete. According to surveys carried out from the 1970s to the beginning of the 2000s, in the lower, 650 km long free-flowing section of the Volga (from the Volgograd hydropower dam to the Caspian Sea), three major populations of the sterlet could be distinguished, with minor morphological differences between individuals. The spawning grounds of the three subpopulations were well separated and, to some extent, so were their foraging areas. However, two subpopulations mostly migrated along overlapping routes to their spatially distinct spawning grounds (Khodorevskaya et al. 2009, Kalmykov et al. 2010). During the period of the surveys, the Volga sterlet populations were fully self-sustaining and their genetic integrity was not affected by stocking.

Fish stocking does not take into account the preservation of the genetic integrity of wild sterlet populations in Hungary. Fishery managers generally do not address the question of the origin of the broodstock from which the sterlet intended for release are derived. Sometimes the juveniles from Danube-origin broodstock are placed in the Tisza and vice-versa. A further problem of the repeated stocking actions is that eggs and sperm are obtained from only a limited number of broodstock in an artificial propagation, so the genetic diversity of propagated fish is below the level of wild populations. In order to avoid inbreeding, at least fifty effective breeding fish should be included in reproduction (Dodge and Mack 1996), but this condition is generally not met in Hungarian practice. The ex-situ broodstock kept in aquaculture are likely to carry only a narrow spectrum of the gene pool of wild sterlet populations, and it is also assumed that they can be characterized as a genetic mixture of several wild subpopulations. It is not known whether, and to what extent, the stocking of aquaculture-reared fish affects the genetic variability of declining wild populations.

Invasive predators

The sterlet is a benthic fish that lives in the deeper parts of the riverbed, and is therefore inaccessible to most piscivorous birds. However, the cormorant (*Phalacrocorax carbo*) is able to dive to a depth of 6-10 m, in some cases up to 35 m, to search for fish hiding near the bottom (Grémillet et al. 2006), which is why sterlet are within their food spectrum (Figure 26). The cormorant catches fish effectively in turbid water, under moderate light conditions, or even in the darkness of night. It can visually detect fish underwater from a distance of less than 1 meter, but its ears are capable of detecting vibrations that travel through the water, allowing them to navigate underwater. Penguins and turtles, among others, have a similar ability (Larsen et al. 2020).

The cormorant nested in large colonies in the fish-rich regions of the Carpathian basin in the 19th century (Lázár 1874), mainly along the larger river floodplains. By the end of the 19th century, the European population had declined significantly, probably as a result of extensive habitat alteration due to river regulation. In the first half of the 20th century, the cormorant no longer bred in Hungary, and only migrating individuals were sporadically observed during the winter periods. At the end of the 1940s, a few breeding pairs reappeared in the reed beds of Lake Little Balaton. Subsequently, nesting colonies were formed in increasing numbers (Keve 1973). In the second half of the 20th century, the European cormorant stock increased by almost two orders of magnitude as a result of climate changes, as well as restrictive conservation regulations and the development of wetlands. At the beginning of the 21st century, the size of the European cormorant population was estimated at 1.7-1.8 million individuals (Kindermann 2008). The Hungarian population of the subspecies *P. c. sinensis* (which is distributed in central, eastern and southern Europe as well as Asia) increased to about 1,800-3,000 breeding pairs by the end of the 20th century, with an additional 25,000-30,000 wintering migrants arriving from the north in late autumn and winter. In the harsher winters, when the waters freeze, a significant part of the overwintering birds migrate further south. Since the beginning of the 21st century, the population in Hungary has declined moderately (Hungarian Ornithological and Nature Association 2021b).

In larger water areas, the damage to fisheries caused by cormorants can usually be estimated based on the observed numbers of individuals, their residence time and their daily food requirements. The annual fish consumption of cormorants can be estimated at 2,428 tons in Hungary (Faragó et al. 2006). In addition to direct fish consumption, beak wounds can also cause losses in the fish stock. Wounds on the fish's skin are more difficult to heal in the cold winter months, and a significant number of injured and weakened individuals die as a result of infections. An additional problem is that fish disturbed in their hibernation become restless and often flee to the colder, shallow litoral waters, reducing their likelihood of surviving the winter period.

Figure 27: Sterlet from the stomach of a shot cormorant on the Danube (Photo: T. Dudás)

According to the opinion of the managers of fishing waters, the cormorant's fish consumption has affected the sterlet population of Hungarian rivers, especially the Danube. Some verbal reports and photographs certify the consumption of sterlet by cormorants (Figure 26). During the analysis of the stomach contents of cormorants, shot during population control efforts in recent years along the Danube and Tisza rivers, sterlet were found in relatively small numbers among the food components.

Alien fish species

Among the non-native fish species occurring in the Danube, the presence of the Siberian sturgeon (*Acipenser baerii*) may have an impact on the wild populations of the sterlet. The distribution of Siberian sturgeon in Siberia is common in the major river systems from the Ob to the Kolyma and in Lake Baikal. In Europe, its natural population is known only in the Pechora River (Berg 1948). In Hungary, a few fish farms have been breeding them since 1982. A hybrid with the sterlet has also been reared. In 1996 and 1997, 700 kg of these hybrid fish were stocked, without a permit, in the Hungarian stretch of the Drava (Pintér 1989). The hybrid fish has also been stocked in closed fishing waters and garden ponds several times since the early 2000s. Escaped specimens from fish farms or anglers' ponds have been found occasionally in the Slovak-Hungarian stretch of the Danube (Masár et al. 2006, Farský et al. 2013).

Natural reproduction of the Siberian sturgeon is not typical in European waters, but hybrid individuals have been recorded in the German-Austrian section of the Danube near Jochhenstein (Ludwig et al. 2009). Since the 1970s, several attempts have been made to reintroduce the sterlet in the German and Austrian sections of the Danube, but there is no evidence for the successful establishment of a self-sustaining population. Genetic and external morphological analysis of fish collected at Jochhenstein showed that 7 out of 14 specimens were sterlet, one was a Siberian sturgeon, and six specimens were identified as hybrids of the two species. Based on these results, the authors concluded that the Siberian sturgeon reproduced naturally and hybridised. Under altered habitat conditions, sturgeon are prone to interspecific hybridisation, and the occurrence of Siberian sturgeon in the Danube water system potentially threatens the genetic integrity of natural sterlet populations (Ludwig et al. 2009).

Climate change

Climate change scenarios for the Carpathian Basin predict a difficult future for water-related problems, not only because of rising temperatures but also because of the shift in precipitation patterns within the year. The greatest warming is expected to occur in the summertime, with a decrease in precipitation also likely during this period. The more extreme precipitation distribution associated with climate change will lead to extreme run-offs, resulting in more frequent major floods along the rivers. In the context of prolonged rainfall deficits, low flows will become more regular, with evaporation exceeding the sum of the flows from the catchments. Changing hydrological, hydro-morphological and hydro-chemical processes have a major impact on the biota and habitat diversity of river systems.

Hydrological processes associated with climate change may modify the habitat of the sterlet, its reproductive success, as well as the probability of the survival of individuals during early development. Rising temperatures directly affect fish activity, migratory behaviour and the development of their reproductive organs. If the sterlet adapts slowly to the relatively rapid changes in the environment caused by climate change, a significant decline or extinction of its population can be expected in the fluvial system of the Danube.

Assessment of external pressures on sterlet populations

Effective species conservation requires an assessment of the impacts of different pressures on the structure or function of populations. Increasing environmental pressures, resulting from social and economic drivers, have complex and quantifiably difficult impacts on fish populations in rivers. Anthropogenic pressures generally alter the ecological state of habitats (the physical environment surrounding the population and its chemical and biological components), which have subsequent impacts on the populations. The questions to be decided when evaluating anthropogenic pressures is how and to what extent habitat alteration affects sterlet populations.

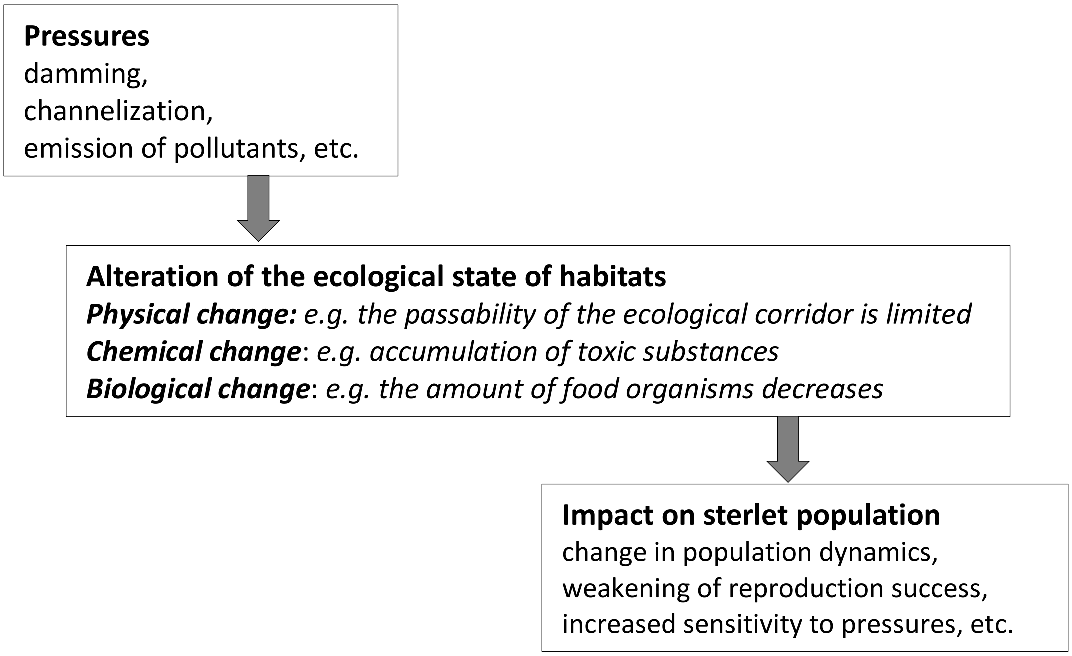

Figure 28: Schematic relationship of the adverse impacts appearing in the sterlet population with anthropogenic pressures

Changes in the habitat of a population do not always result in a directly detectable change in the population, it is therefore appropriate to distinguish between potential and actual impacts:

- Signs of a **potential impact** are not detectable because their appearance can only be expected. Assumed and unproven impacts are generally considered as potential. The potential impact that threatens a population can be characterized by a certain risk level, which depends on the probability of occurrence of a potential impact and the severity of its expected consequences.
- Signs of an **actual impact** are detectable and can include changes in the growth, development, and lifespan of the individuals in the population, as well as changes in the population's size or reproductive capacity, etc. A negative actual impact can be characterized by causing a certain degree of damage, which depends on the spatial extent of the impact and the severity of its consequences.

The following simple scheme can be used to evaluate the estimated risk (**R**) of a potential impact:

Estimated probability (**P**) of the impact occurring is scored according to two options:

- 1 – low, less than 50 % probability within 5 years (1 generation period)
- 2 – high, more than 50 % probability within 5 years

Estimated severity (**S_P**) of the expected consequence of the potential impact is scored according to two possibilities:

- 1 – moderate, less than 20% reduction in the number of breeding individuals in the population within 10 years
- 2 – significant, more than 20% reduction in the number of breeding individuals in the population within 10 years

The degree of risk is calculted as $R = P + S_P$

- low risk if R = 2
- medium risk if R = 3
- high risk if R = 4

The following scheme can be used to assess the damage (**D**) associated with an actual impact:

Estimated spatial extent (**E**) of the damage is scored according to two options:

- 1 – local, impact on a river section less than 200 km in length
- 2 – regional, impact on a river section more than 200 km in length, or across several river sections

Estimated severity (**S_A**) of damage is scored according to two options:

- 1 – moderate, quantitative reduction or absence of reproductive individuals in the affected population being less than 20%
- 2 – significant, quantitative reduction or absence of reproductive individuals in the affected population being more than 20%

The degree of damage is calculated as $D = E + S_A$

- low damage if D = 2
- medium damage if D = 3
- high damage if D = 4

The impacts related to the different pressures have been analysed according to the following criteria:

- persistence of tolerable water quality
- availability of food organisms
- possibility of successful reproduction
- disturbance-free early development
- surviving critical periods (winter, flood, drought)

In Table 7, the anthropogenic pressures were ranked by summing up the risks or damages of the impacts attributable to them.

Table 2: Analysis of adverse impacts on sterlet populations in terms of the persistence of tolerable water quality

Impact analysis **- tolerable water quality**		**adverse impact**			**risk**			**damage**		
Pressures		none	potential	actual	probability	severity	**degree of risk**	extent	severity	**degree of damage**
River regulation	damming			x				2	1	**3**
	channelization			x				2	1	**3**
Navigation			x		1	1	**2**			
Diffuse water pollution	nutrients		x		2	1	**3**			
	pesticides		x		2	1	**3**			
Point source water pollution				x				1	1	**2**
Accidental water pollution			x		1	2	**3**			
Pollution caused by microplastics		x								
Control of mosquito populations		x								
Fisheries management for angling		x								
Invasive predators	cormorant	x								
Alien fish species	Siberian sturgeon	x								
Climate change				x				2	1	**3**

Table 3: Analysis of adverse impacts on sterlet populations in terms of the availability of food organisms

Impact analysis **- availability of food organisms**		**adverse impact**			**risk**			**damage**		
Pressures		none	potential	actual	probability	severity	**degree of risk**	extent	severity	**degree of damage**
River regulation	damming			x				2	2	**4**
	channelization			x				2	1	**3**
Navigation			x		2	1	**3**			
Diffuse water pollution	nutrients		x		1	1	**2**			
	pesticides		x		1	1	**2**			
Point source water pollution			x		2	1	**3**			
Accidental water pollution			x		1	2	**3**			
Pollution caused by microplastics			x		2	1	**3**			
Control of mosquito populations				x				2	2	**4**
Fisheries management for angling		x								
Invasive predators	cormorant	x								
Alien fish species	Siberian sturgeon	x								
Climate change			x		2	1	**3**			

Table 4: Analysis of adverse impacts on sterlet populations in terms of the possibility of succesful reproduction

Impact analysis - possibility of successful reproduction		**adverse impact**			**risk**			**damage**		
Pressures		none	potential	actual	probability	severity	**degree of risk**	extent	severity	**degree of damage**
River regulation	damming			x				2	2	**4**
	channelization			x				2	1	**3**
Navigation			x		2	1	**3**			
Diffuse water pollution	nutrients		x		1	1	**2**			
	pesticides			x				1	1	**2**
Point source water pollution				x				1	2	**3**
Accidental water pollution			x		1	1	**2**			
Pollution caused by microplastics		x								
Control of mosquito populations			x		1	1	**2**			
Fisheries management for angling			x		1	1	**2**			
Invasive predators	cormorant	x								
Alien fish species	Siberian sturgeon		x		1	1	**2**			
Climate change				x				2	1	**3**

Table 5: Analysis of adverse impacts on sterlet populations in terms of disturbance-free early development

Impact analysis - disturbance-free early development		**adverse impact**			**risk**			**damage**		
Pressures		none	potential	actual	probability	severity	**degree of risk**	extent	severity	**degree of damage**
River regulation	damming			x				2	2	**4**
	channelization			x				2	1	**3**
Navigation			x		2	1	**3**			
Diffuse water pollution	nutrients		x		1	1	**2**			
	pesticides		x		1	1	**2**			
Point source water pollution				x				1	2	**3**
Accidental water pollution			x		1	2	**3**			
Pollution caused by microplastics			x		2	1	**3**			
Control of mosquito populations			x		2	1	**3**			
Fisheries management for angling		x								
Invasive predators	cormorant	x								
Alien fish species	Siberian sturgeon	x								
Climate change				x				2	1	**3**

Table 6: Analysis of adverse impacts on sterlet populations in terms of the probability of survival during critical periods in the life cycle

Impact analysis - survival during critical periods		**adverse impact**			**risk**			**damage**		
Pressures		none	potential	actual	probability	severity	**degree of risk**	extent	severity	**degree of damage**
River regulation	damming		x		2	1	**3**			
	channelization			x				1	1	**2**
Navigation			x		2	1	**3**			
Diffuse water pollution	nutrients		x		2	1	**3**			
	pesticides		x		2	1	**3**			
Point source water pollution				x				1	1	**2**
Accidental water pollution			x		1	2	**3**			
Pollution caused by microplastics		x								
Control of mosquito populations			x		1	1	**2**			
Fisheries management for angling			x		1	1	**2**			
Invasive predators	cormorant			x				2	1	**3**
Alien fish species	Siberian sturgeon	x								
Climate change				x				2	1	**3**

Table 7: Assessment of pressures causing adverse effects on sterlet populations.

		potential impacts						**actual impacts**					
		degree of risk						**degree of damage**					
Pressures		water quality	food organisims	reproduction	early development	critical periods	**total risks**	water quality	food organisims	reproduction	early development	critical periods	**total damages**
River regulation	damming					3	**3**	3	4	4	4	0	**15**
	channelization							3	3	3	3	2	**14**
Navigation			3	3	3	3	**14**						
Diffuse water pollution	nutrients	3	2	2	2	3	**12**						
	pesticides	3	2		2	3	**10**			2			**2**
Point source water pollution			3				**3**	2		3	3	2	**10**
Accidental water pollution		3	3	2	3	3	**14**						
Pollution caused by microplastics			3		3		**6**						
Control of mosquito populations				2	3	2	**7**		4				**4**
Fisheries management for angling				2		2	**4**						
Invasive predators	cormorant											3	**3**
Alien fish species	Siberian sturgeon			2			**2**						
Climate change			2	2	2	2	**11**						

According to the results of the impact analysis, among the pressures associated with actual impacts on sterlet populations, the construction of dams and barrages, improving river navigability and point source water pollution are the most significant. Among the pressures associated with potential impacts that endanger the sterlet populations, navigation, extraordinary and diffuse water pollution, and climate change are particularly notable. The control of mosquito populations and water pollution from microplastics are also worth mentioning.

Table 8: The ranking of pressures resulting in actual and potentail impacts on sterlet populations

		risk	**damage**	**total**
River regulation	damming	3	15	**18**
	channelization		14	**14**
Navigation		14		**14**
Accidental water pollution		14		**14**
Point source water pollution		3	10	**13**
Diffuse water pollution	nutrients	12		**12**
	pesticides	10	2	**12**
Control of mosquito populations		7	4	**11**
Climate change		11		**11**
Pollution caused by microplastics		6		**6**
Fisheries management for angling		4		**4**
Invasive predators	cormorant		4	**4**
Alien fish species	Siberian sturgeon	4		**4**

For some of the pressures assessed, there is insufficient information to make a proper evaluation due to a lack of research exploring the hypothesised impacts. Therefore, a greater number of actual impacts are likely to cause damage to sterlet populations than is apparent from this analysis.

Conservation plan for sterlet

Strategic planning

The overall objective of this conservation plan is to halt the decline of the wild sterlet population and to promote their recovery in Hungary. This conservation plan addresses the issues that need to be resolved in Hungary. Since sterlet is a non-fishable species in Hungarian rivers, the regulation of fishing activities is not relevant at this time. There is a well-organised fish guard network within the Hungarian National Anglers' Association which discourages poaching and illegal trade opportunities. The artificial breeding and rearing of sterlet on a commercial scale has been carried out for decades in Hungary. Facilities that can be utilized for this strategic plan already exist in Hungary, including several fish farms that regularly propagate sterlet as well as a sturgeon gene bank. The tasks to be carried out in order to achieve the overall objective can be grouped into four strategic objectives (SO):

SO 1: The mitigation of anthropogenic pressures that modify key fish habitats.

SO 2: Increasing the extent of restored and protected sterlet habitats.

SO 3: Improving the viability of self-sustaining sterlet populations.

SO 4: Increasing public awareness and sterlet conservation efforts.

These strategic objectives are intended to occur over a longer time span (>5 years) and are aimed at mitigating the impacts that limit or threaten the survival of the sterlet population. The means to achieving a strategic objective is defined by shorter-term, tactical objectives (TO) that are simplified and address specific problems. Tactical objectives can be achieved through actions and management measures, for which recommendations are included in the conservation plan.

Mitigation of anthropogenic pressures that modify key fish habitats

Conservation measures can be preventive, especially when targeting human activities that exert 'pressures' on the environment. Prevention can be achieved by prohibiting, restricting or regulating (in accordance with sustainability and precautionary principles) activities that cause disturbances or threaten habitats.

The tactical objectives and recommended actions (A) and measures to mitigate or stop the anthropogenic pressures on sterlet habitats are summarized in Table 9.

The improvement of the longitudinal connectivity and ecological status of watercourses, and indirectly the protection of migratory fish species, is reflected in the Hungarian implementation strategy of the EU Water Framework Directive (WFD) and the Hungarian river basin management plans.

Table 9: Tactical objectives and recommended actions to mitigate or stop anthropogenic pressures on sterlet habitats

SO 1 The mitigation of anthropogenic pressures that modify key fish habitats	
Tactical objectives	**Recommended action**
TO 1.1 Reduction in the number of facilities impeding fish migration along the major rivers and their tributaries	A 1.1.1 Prohibiting further construction of obstructive facilities
	A 1.1.2 The removal of obstructive facilities, where the conditions are met
	A 1.1.3 Ensuring passability by modifying the obstructive facility
	A 1.1.4 Ensuring passability by constructing fish passes
	A 1.1.5 Promoting safe downstream fish migration in the area of hydropower plants – the development of devices to guide fish to safe passage
	A 1.1.6 Promoting safe downstream fish migration in the area of hydropower plants – modifying turbines using solutions that are less harmful to fish
TO 1.2 Ecological considerations are taken into account when improving river navigability	A 1.2.1 Avoid modification of the natural bank and riverbed sections
	A 1.2.2 Designation of a restricted width to river waterways, taking into account the protection of sterlet habitats (A 2.1.3)
	A 1.2.3 Reducing the extent of ford dredging
	A 1.2.4 Lowering the height of previously constructed flow control structures
TO 1.3 Using environmentally friendly navigation practices	A 1.3.1 Speed restrictions in known sterlet spawning areas during periods of spawning and the early development of juveniles (April – July)
	A 1.3.2 Design and application of technical solutions to mitigate the disruptive effects of ship traffic
	A 1.3.3 Influencing transport policy making on the development of vessel traffic - Advising the NFM Transport Authority on environmental regulation of shipping and amending legislation.
TO 1.4 Less diffuse pollution along river systems	A 1.4.1 Reduction in agricultural origin nutrient pollution
	A 1.4.2 Pesticide application regulation under the Pesticides Directive
	A 1.4.3 Cultivation of resistant types of plants, water-saving plant cultivation methods
	A 1.4.4 Land-use change (field-grassland, field-forest, field-wetland conversion)
	A 1.4.5 Reduction of sediment and pollutant load from soil erosion and/or surface runoff – protection by planting vegetation
	A 1.4.6 Development of biological filtration fields

TO 1.5 Reducing point source pollution along river systems	A 1.5.1 Establishment of new, modern wastewater treatment plants, upgrading existing facilities to comply with the Wastewater Directive concerning urban waste water treatment
	A 1.5.2 Improving the requirements for the quality of wastewater discharged from industrial plants to the receiving watercourse
	A 1.5.3 Filtering internal waters from agricultural areas before discharging into the receiving watercourse
TO 1.6 Reduction in the likelihood of accidental water pollution	A 1.6.1 Fulfillment of the EVESO directive on the control of the risks of serious accidents related to hazardous substances
	A 1.6.2 Preparing for the implementation of accident management plans
TO 1.7 Reduction of microplastic pollution	A 1.7.1 Limiting the use of plastic packaging materials
	A 1.7.2 Replacing plastics with natural materials
	A 1.7.3 Collection and recycling of plastic waste

Reduction in the number of facilities impeding fish migration

The basic concept of a fish passage is to create moderate water flow velocities with sills that provide a pathway for fish. Despite increasing implementation and use, there are still issues related to the design and operation of efficiently functioning fish passages, such as maintaining favourable hydraulic conditions under varying water levels and flows. Beyond the limitations, however, the effectiveness of the passages is determined more by how the hydraulic conditions match the needs of fish fauna in the given river and the migratory behaviour of target fish species.

For fish migrating upstream to successfully pass through an obstacle blocking their path, they need to find the entrance to the facility. The placement and design of the entrance and the maintenance of a water flow that attracts fish to the entrance are particularly important. Water flow affects fish in a complex way, and knowledge on the responses of different species is still incomplete (NMFS 2004, Williams et al. 2014), this is particularly true for sterlet.

The details of downstream migration are less well understood than upstream migration. Generally, there are no obstacles to downstream migration, but there may be dangerous structures such as hydroelectric turbine chambers that can cause significant injury and mortality to fish passing through them. Discouraging fish from dangerous places is sometimes difficult. Electric fish barriers can be used effectively on smaller rivers to divert fish, while innovative solutions are needed to develop diversion systems that work well on larger rivers (Pavlov and Mikheev 2017).

Integration of ecological principles in the development of navigation

The use of the Danube as a waterway puts pressure on the river ecosystem and its associated ecosystem services. However, there are no generally feasible technical solutions to eliminate the effects of these pressures. In view of the unfavourable changes, the strategy of sustainable development and the enforcement of the ecological principles defined in the National Nature Conservation Basic Plan must be taken into account in the transport policy decisions supporting the development of the Danube navigation infrastructure and the increase in traffic.

Reduction of pollution along river systems

Water pollution reduction efforts are being addressed through measures set out in river basin management plans and developed through an extensive planning process, based on the objectives of the EU WFD, the EU Pesticides Directive, the EU Urban Wastewater Directive, the EU Nitrate Directive and the National Plant Protection Action Plan.

The effects of measures to improve water quality (wastewater treatment, sediment removal by dredging, etc.) should be monitored in order to maintain healthy and species-rich habitats. The long-term changes in fish stocks, population dynamics of species, indicators of pressures, etc. should be examined. There is a lack of knowledge about the ecotoxicological risks to aquatic life posed by increasing levels of microplastics, especially fish populations. From the perspective of food and environmental safety, it is imperative to investigate the effects of plastics of different compositions, and the pollutants adsorbed by them, on fish.

Restoration and protection of habitats

Conservation measures can restore the habitats of sterlet populations. Restoration measures are primarily effective when addressing the effects of river regulations and pollutant emissions.

The tactical objectives and recommended actions intended to increase the extent of restored and protected sterlet habitats are summarized in Table 10.

Table 10: Tactical objectives and recommended actions to increase the extent of restored and protected sterlet habitats

SO 2: Increasing the extent of restored sterlet habitats	
Tactical objectives	**Recommended action**
TO 2.1 More information and less uncertainty about sterlet habitat distribution, habitat needs and migration routes	A 2.1.1 Research, development – evaluation of existing methodologies for the documentation of the physico-chemical and spatio-temporal characteristics of habitat types and habitat use
	A 2.1.2 Development and operation of telemetry monitoring for the tracking of sterlet migration patterns and the localisation of sterlet habitats along major rivers
	A 2.1.3 Mapping of existing habitats from which habitats proposed for protection can be designated, identification of former and potential habitats suitable for restoration
TO 2.2 Improving the function of the river ecological corridor on larger rivers	A 2.2.1 Monitoring the effectiveness of existing fish passes and the identification of facilities limiting the migration of sterlet
	A 2.2.2 Improving the efficiency of fish passages based on the parameters of fish ways that are passable for sterlet
	A 2.2.3 Demolition of functionally outdated in-

	stream facilities
TO 2.3 Adjusting the hydromorphological diversity of regulated river sections towards a more natural state	A 2.3.1 Maintenance of original open floodplains, expansion of the flooded area of floodplains
	A 2.3.2 Improvement in the water supply of the original open floodplains and the flooded area of floodplains
	A 2.3.3 Reduction of river bed incisions that are deeper than the natural state
	A 2.3.4 Creation of a secondary channel through the filled area between the groynes by partial demolition of the bank end of the groynes
TO 2.4 Improving the water quality in river habitats	A 2.4.1 Ensuring sufficient water exchange in side branches - improvement in their connectivity to the main arm
	A 2.4.2 Dredging up silted tributaries for water quality
	A 2.4.3 Restrict land use in floodplains that are periodically flooded
TO 2.5 Ensuring the coordination of habitat restoration actions	A 2.5.1 Establish a national management group responsible for the coordination and implementation of all activities related to habitat restoration and monitoring
	A 2.5.2 Preparing feasibility studies for habitat restoration and proposals for pilot restoration actions
TO 2.6 Changing the management practices of river fisheries’ long-term stocking programmes of artificially propagated fish as attitudes supporting habitat restoration spread	A 2.6.1 Raising the awareness among angling communities about the possibilities and benefits of restoring river habitats
	A 2.6.2 Developing and supporting river habitat restoration plans involving angling communities

An important task of habitat protection and restoration is to identify and research key water bodies and to ensure the long-term maintenance of biological functions associated with habitats. The interests of conservation-oriented habitat protection often coincide with the interests of fisheries management in natural waters, but the focus of the latter is on increasing populations of exploitable fish species.

When identifying habitats essential for the conservation of sterlet populations, attention must be paid to areas that represent a bottleneck in the species' development cycle (breeding, early development and wintering). In this context, it is necessary to locate spawning, nursery and wintering sites and to assess their ecological status. A priority should be the protection of those habitats that are considered favourable for sterlet. If the extent of habitats providing suitable conditions for sterlet is limited, then the possibilities for the restoration of already existing habitats or the establishment of new habitats should be investigated.

Improving the viability of populations

The tactical objectives and recommended actions that can improve the viability of sterlet poulations are summarized in Table 11.

Table 11: Tactical objectives and recommended actions to improve the viability of sterlet populations

SO 3: Improving the viability of self-sustaining sterlet populations	
Tactical objectives	**Recommended action**
TO 3.1 More information becomes available on the dynamics of sterlet populations	A 3.1.1 Research, development – evaluation of population dynamics including growth, reproduction, mortality rate, abundance, etc. – exploring the critical bottleneck in ontogeny
	A 3.1.2 Development and operation of permanent monitoring systems on sterlet populations
	A 3.1.3 Assessing long-term changes in populations - monitoring anthropogenic impacts and the success of conservation actions
	A 3.1.4 Modelling sterlet populations to predict their response to angling (or lack thereof)
	A 3.1.5 Estimating the impact of cormorant on sterlet populations
TO 3.2 Improving the effectiveness of sterlet stocking by preserving the integrity of wild populations	A 3.2.1 Analysis of the genetic structure of wild sterlet populations in Hungary and the Middle Danube – confirm or reject the hypothesis of a metapopulation and the occurrence of reproductive polymorphisms
	A 3.2.2 Control of the genetic quality (purity, diversity, origin) of sterlet released into rivers – set up a laboratory providing information to the fisheries authority
	A 3.2.3 Ensure that the fish to be released are derived from broodstock captured from the same river section that is to be stocked
	A 3.2.4 Reducing the risk of inbreeding – involving a sufficient number of efficient spawners in the reproduction – development of a long-term plan to preserve genetic diversity
	A 3.2.5 Using telemetry to track the migration of specimens introduced from hatcheries – a comparative study on the effects of the rearing conditions of the fish and the impact of the release process
TO 3.3 Cessation of the use of chemical treatments for the eradication of mosquito populations along rivers	A 3.3.1 Evaluation of the impact of chemical treatments on sterlet food sources
	A 3.3.2 Prohibition of chemical treatments along major rivers, especially near protected areas
	A 3.3.3 Use of biological methods for the control of mosquito populations
TO 3.4 Reducing the risk of the Siberian sturgeon and other alien sturgeons	A 3.4.1 Banning the introduction of non-native sturgeon species in angling ponds
	A 3.4.2 Prohibiting the marketing of non-native sturgeon species as ornamental fish
	A 3.4.3 Increased official control of sterlet shipments released into rivers (A 3.2.2)

	A 3.4.4 Enhancing security measures to prevent escape from fish farms into rivers

Development of research and monitoring of sterlet population

The starting point for this sterlet conservation strategy is to understand the causal links between human activities and population changes, and their cumulative effects. Understanding these processes raises a number of questions that require targeted studies and surveys.

The task is to monitor and document changes in sterlet populations. In Hungary, there is no monitoring system for sturgeon or sterlet, unlike the research practices in many countries along the Danube. By evaluating internetional experiences, appropriate procedures should be defined for the establishment of a sterlet monitoring system on Hungarian rivers. Continuous surveys can provide information on population dynamics and the effectiveness of habitat restoration and stock enhancement measures.

Sterlet stocking

The decision-making process related to sterlet stocking is guided by a series of questions such as what is shown in Figure 29. Stocking is usually based on individual decisions by angler associations, and the purchase sources may be different. Regulations regarding the genetic quality and control of released fish has not been established, so it would be advisable to set up a laboratory operating independently of the fish breeders that is able to provide information to the fisheries authority on the genetic quality of fish that are introduced into the rivers. Analysis of the genetic aspects of wild sterlet populations in Hungary and the Middle Danube can provide essential information for the planning of effective, long-term conservation measures. The results of these analyses could be used to confirm or reject the hypothesis of a metapopulation and the occurrence of reproductive polymorphisms (Currens et al. 1990). Until these questions are answered, efforts should be made to ensure that the fish released into the rivers are preferably derived from broodstock captured from the same river section that is to be stocked. At the same time, the risk of inbreeding should be considered and avoided by utilizing 50 effective spawners for propagation (Dodge and Mack 1996).

Preventing the spread of non-native sturgeons

The presence of the Siberian sturgeon is indicated only by sporadic data in the Hungarian section of the Danube and there is no evidence of its reproduction in the wild. Paragraph 28 (17) of Decree 133/2013 (29.XII.) of the MRD clearly prohibits the release of non-native fish species into natural waters in order to protect the native fish populations in Hungary. The fishery management authorities must prevent the introduction of Siberian sturgeon into natural waters in accordance with the legislation. In this context, restrictions on the stocking of fishing ponds as well as prohibitions on the marketing of Siberian sturgeon as ornamental fish should be considered. Increased attention should also be given to the regulation of sterlet shipments released into rivers. Several times in the past, fish producers have sold Siberian sturgeon or hybrid specimens crossed with sterlet, which is usually not noticed by fisheries managers.

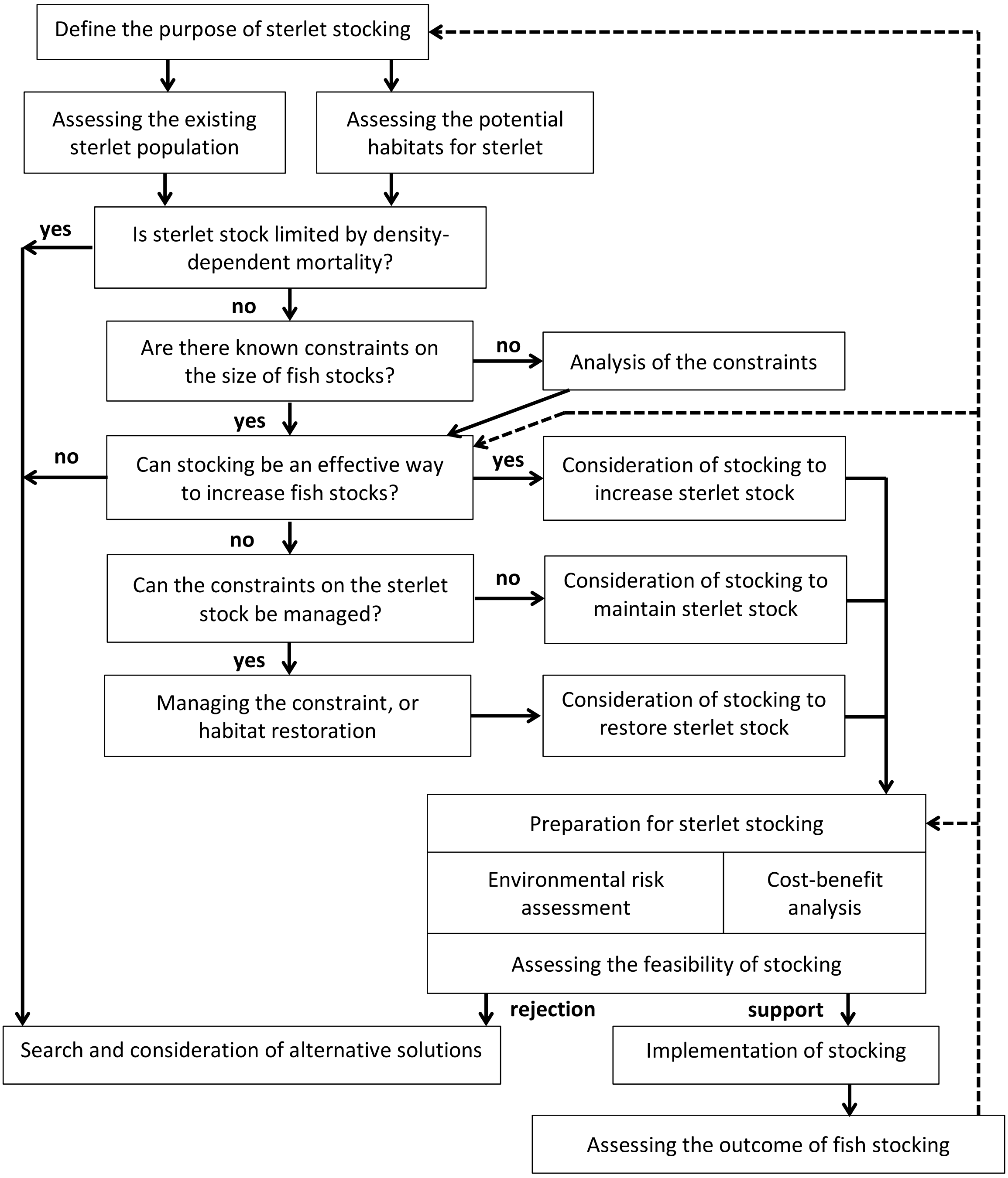

Figure 29: Decision-making process for sterlet stocking

Development of mosquito control methods

The impact of chemical treatments for the eradication of mosquito populations is less known for sterlet. A significant decrease in the biomass of aquatic insects is evident after such treatments, and this affects the abundance of food organisms available for sterlet. The reduction in food availability may have an impact on sterlet populations, but targeted research is recommended to explore the relationship.

Prioritizing the wider use of biological mosquito control methods is particularly justified from the point of view of nature conservation and the preservation of aquatic life. Biological treatment methods are effective at preventing the spread of mosquito-borne diseases while causing much less toxic pollution. In biological mosquito control methods utilizing a biological agent (e.g. VectoBac 12 AS), the active ingredient is a toxic protein from *Bacillus thuringiensis var. Israelensis.* The biological agent applied to the surface of the water is ingested by aquatic organisms, and it selectively kills only the larvae of biting midges (*Culicidae*) and humpback midges (*Simuliidae*). For other animals, the biological agent poses a negligible risk. Wetlands, which are of decisive importance for mosquito breeding, are usually located in areas that are difficult to access, densely vegetated and possibly flooded. Mosquito breeding sites that are accessible by car or watercraft are sprayed with a high-pressure sprayer. If the sites are inaccessible by car or watercraft, spraying can be done on foot with a hand-held sprayer, or, in larger wetlands, by aerial spraying, where a granular active substance is sprayed that falls through the foliage of trees and does not adhere to vegetation. With the timely treatment of such biological controls, the mass appearance of biting mosquitoes can be prevented to some extent.

Raising public awareness

Raising public awareness can significantly contribute to the successful implementation of actions and measures aimed at the conservation of sturgeon populations (Sandu et al. 2013). The implementation of the Hungarian action plan for sterlet conservation will require broad support at various levels, from decision makers to the local public. Effective communication is essential to explain the objectives to be achieved, to convince stakeholders and to increase the level of support for a long-term programme.

The tactical objectives and recommended actions to raise public awareness are summarised in Table 12.

Table 12: Tactical objectives and recommended actions to raise public awarenes

SO 4: Increasing public awareness and sterlet conservation efforts	
Tactical objectives	**Recommended action**
TO 4.1 Awareness of sturgeon/sterlet conservation actions is increased	A 4.1.1 Identification of the main target groups and their possible contribution to sterlet conservation
	A 4.1.2 Develop and implement a targeted communication plan to raise stakeholder awareness - preparation of key messages.
	A 4.1.3 Emphasising the historical importance of sturgeon/sterlet fish
	A 4.1.4 Emphasising the causes leading to the decline of populations
	A 4.1.5 Employ suitable channels (TV, newspapers, magazines, etc.) and materials adapted to each target group (flyers, brochures)
	A 4.1.6 Organization of information meetings, workshops, conferences, etc. to address specific topics to different groups of people

	A 4.1.7 Utilisation of the internet (website, Wikipedia, forums, Facebook, etc.) to advertise the importance of sterlet conservation
TO 4.2 More frequent communication and information sharing between stakeholders	A 4.2.1 Strengthen inter-sectoral cooperation, such as nature conservation, fisheries agencies and water management authorities to develop a common approach towards sterlet conservation
	A 4.2.2 Organize regular expert meetings to increase the knowledge on sturgeon conservation and to organize the transfer of knowledge from science to managers
TO 4.3 Adequate funding for long-term conservation actions	A 4.3.1 Support from EU funds are needed to implement measures for sterlet conservation in Hungary
	A 4.3.2 Hungarian programming of EU funds needs to include sterlet conservation measures, according to this action plan

Summary

The importance of the sterlet was significant in the major rivers of Hungary in historical times, but in the 20th century, especially near its end, a decline in the sterlet population was indicated by the decreasing catches of fishermen and anglers. Among the notable external pressures that endanger the sterlet populations are: the construction of dams and barrages, the development of river waterways, increasing ship traffic, and water pollution. Also worth mentioning is the systematic elimination of mosquito populations utilizing chemical agents.

The overall objective of this conservation plan is to stop the decline of the remaining sterlet population and to promote their recovery in the major rivers of Hungary. The numerous tasks to be carried out in order to achieve this overall objective can be grouped into four strategic objectives, which are intended to be completed over a period of more than five years:

SO 1: The mitigation of anthropogenic pressures that modify key fish habitats.

SO 2: Increasing the extent of restored and protected sterlet habitats.

SO 3: Improving the viability of self-sustaining sterlet populations.

SO 4: Increasing public awareness and sterlet conservation efforts.

The strategic objectives are aimed at mitigating the impacts that limit or threaten the survival of the sterlet population, partly through scientific research efforts. In order to achieve these, the action plan defines 20 tactical tactical objectives, for which 76 different actions and measures are recommended.

River fisheries managers often argue that the decline in the natural reproduction of sterlet can and should be replaced by the introduction of artificially propagated fish because "natural spawning grounds are no longer functional". This practice is a symptomatic treatment which does not deal with the root causes of the problem. The conservation plan proposed here focuses on different solutions. The starting point is the identification of pressure-and-impact relationships between human activities and changes in sterlet populations, as well as the understanding of their cumulative effects. Exploring these interactions raises a number of questions that will require targeted studies and surveys.

The sterlet is an „umbrella species” and its complex habitat requirements overlap with those of many other fish species, so the protection and restoration of sterlet habitats is also part of the conservation of many other fish species in riverine faunas. The concept behind the conservation plan is to improve the reproductive success and natural recruitment of sterlets, both by reducing pressure on populations and by restoring their habitats. However, the scope for conservation measures is limited by the constraints imposed by societal expectations regarding the economic exploitation of rivers.

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