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Review

Conservation Status and Effectiveness of the National and International Policies for the Protection and Conservation of Sturgeons in the Danube River and Black Sea Basin

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Abstract: Rivers and their watersheds have been subject to various changes, including biodiversity, caused by anthropogenic activities. The Danube River and Black Sea basin overlap the geographic range of six species of anadromous fish belonging to the family Acipenseridae. Nowadays, they are endangered or at risk of extinction in the wild due to fragmentation and destruction of natural habitats, blocking their migration to spawning grounds, water pollution, and poaching. This paper presents a review of the historical and current distribution and evolution of the sturgeon populations of sturgeon species in the Danube River basin. Conservation status and measures for species protection, conservation, and restoration at the national, regional, and global levels are presented.

Keywords: sturgeons; habitat destruction; overfishing; population depletion; threatened species; extinct sturgeons

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1. Introduction

The Danube River is the second-longest river in Europe and the main tributary of the Black Sea; in a former bay of it, during the early Holocene, it built a delta [1,2], which currently has remained the only significant surface that is nearly undisturbed wetland in Europe. Having its sources in the Black Forest Mountains, along its 2857 km, the Danube crosses or borders 11 countries until it meets the sea, but within its watershed that drains around 30% of central and eastern Europe, overlaps in whole or in part the territory of 19 countries, thus making it the most international river in the world.

Traditionally, according to geological and hydro-geomorphological characteristics, the Danube River is divided into four main sections as follows: (1) the Upper Danube, from its sources until Devin Gate (at the confluence of the Danube and Morava rivers), downstream to Bratislava; (2) the Middle Danube, from Devin Gate to downstream of the Iron Gates Gorge; (3) the Lower Danube, from the Iron Gates until Pătlăgeanca, where the delta begins; and (4) the Danube Delta, where the river splits into three main distributaries—Chilia, Sulina, and Sfântu Gheorghe [3], that led to longitudinal and lateral environmental gradients. Each section overlaps particular geological units and major landforms that have evolved at various geological time scales.

The large geographical extension of the Danube basin and the fact that the river course connects five biogeographical regions [4] are reflected in its biodiversity. However, as it was stressed in the comprehensive paper "Limnologie der Donau", "the hydrofauna of the Danube system differs considerably from that of other European rivers. Its peculiarities can only be explained and understood if one considers the paleogeographic past of the area through which the Danube flows. Two main facts have to be kept in mind: the area of the middle and

lower course of the Danube were never glaciated during the ice age and was covered by a sea during the Miocene and the beginning of the Pliocene. This is how the fauna of the Danube system could survive from the Middle Tertiary up to the present" [5] (p. 115).

Among the first and well documented papers about the fish fauna of the Danube River is that of Marsili [6]. In the 19th century, the interest of biologists was directed almost exclusively to the fish fauna of the upper and middle Danube [7]. At the beginning of the 20th century, studies about the fish fauna of the lower Danube River, its floodplain, and delta were carried out by Antipa [8–11].

During the second half of the 20th century, based on the regional [12–14] and extended studies for the entire Danube River basin [15,16], the number of fish species varied from 102 [15,17] to 115, which is equivalent to almost 20% of the European fish fauna, according to a more recent review [18]. Out of all the fish species recorded in the Danube drainage, approximately 79% live in its main riverbed [14]. With this high number of fish species belonging to 23 families, the Danube is the richest river faunistically in all of Europe [12,17,18].

Many fish species from the Danube River basin have direct economic importance, but sturgeon species are the most economically valuable fishes because they are caviar-producing fishes, and their flesh has also been highly prized since ancient times [19]. For example, in order to have a comparison term, at the beginning of the 20th century, a mature beluga female full of roe was equivalent to five pairs of oxen, the main working animals at that time, usually used as draft animals [20]. In the next century, one kilo of beluga caviar was sold for up to USD 4290 [21].

In the area of the Danube River basin, sturgeons have been economically fished and became an important product on the market since the 13th century [22,23]. In addition, they are ecologically and culturally important species.

Historically, in the Danube River and its main tributaries, there are six native species that belong to the family Acipenseridae: *Acipenser gueldenstaedtii*, *A. nudiventris*, *A. ruthenus*, *A. stellatus*, *A. sturio*, and *Huso huso* [8,9,12,17].

During the 20th century, various anthropogenic factors were involved in the decline of all six sturgeon species and even in the extirpation of populations of some species throughout the Danube River and the Black Sea basin. It is about overfishing and illegal fishing, water pollution, habitat loss, habitat fragmentation, migration disruption, and hydrogeomorphological alterations caused by dams and hydraulic structures [19,24–29].

Significant changes in sturgeon populations' size were reported indirectly by the decreasing number of caught fish and the progressive reduction in size of captured specimens from the middle Danube that has already been noted since the middle of the 19th century, the diminution in size being the consequence partly of the capture of spawning fish and partly of excessive fishing [30].

At the beginning of the 20th century, scientific works were published that warned about the decrease in the populations of Acipenseridae species in the northwest of the Black Sea and the Lower Danube River due to excessive fishing, as well as about the decline of mature and very large breeding specimens and the consequences that would follow [8,11,20]. Later, similar observations were made in other areas of Europe [31]. In the second half of the 20th century, the decline of sturgeon populations became more and more evident. Therefore, national assessments of sturgeon population status were performed in the middle of the 20th century [32], and comprehensive analyses of sturgeon population decline from the Danube River basin have been published since the end of the 20th century [17,33,34]. The results only confirmed what had already been reported about all the species in the world of the family Acipenseridae [35]: all sturgeon species extant in the Danube River basin are relict of once very widespread populations; they are highly threatened according to the IUCN (International Union for Conservation of Nature) Red List, and programs to conserve the remnant populations are imperative. National, regional, and European plans were established to recover the sturgeon population [36–39].

Because the Danube is an international river, conservation programs for sturgeon must be a cooperative action not only of the riparian countries but also of the countries bordering the Black Sea. This requirement was highlighted by Grigore Antipa in 1933, during the General Assembly of the Commission Internationale pour l'Exploration Scientifique de la Méditerranée (CIEM). At that time, Romania was the only country among the countries bordering the Black Sea where, for more than 40 years, thanks to the fishing law enacted in 1896, drastic measures had been applied on its territory to protect the reproduction and growth of fry and juvenile sturgeons [20].

2. Acipenseridae Species Diversity, Their Distribution, and Their Conservative Status in the Danube River and the Black Sea

2.1. General Overview

Sturgeons, the species of family Acipenseridae, order Acipenseriformes, are among the most ancient ray-finned fish [40]. These primitive bony-fish, sometimes described as "living fossils" [41], originate from the Cretaceous, but their closest relatives have existed since the Lower Jurassic [42]. It was stated that Acipenseriformes evolved from a paleonisciformes ancestor through a paedomorphic reduction of the skeleton and specialization of the feeding system [40]. The geographic distribution of discovered fossils and recent taxa is from the Holarctic region, which is consistent with the current geographical range of living things [40,43–45]. Because the majority of sturgeon species [11] occur in the Ponto-Caspian region, this fact suggests that Acipenseriformes fishes originated in a palaeogeographic marine area that corresponds with Europe [46], and the two extant sister families diverged prior to the Late Cretaceous [40].

In the middle Danube River basin, indeterminate acipenseriform fossils were recorded in nonmarine formations belonging to the uppermost Cretaceous from the Haţeg Basin, located in the South Carpathians [44]. The undoubted remains of *Acipenser* genus were recorded from the Pliocene deposits in the same area, Romania [41].

However, with eight of the 25 currently recognized living species [47], albeit the number of species in the genus *Acipenser* remains controversial [48,49], the European waters have the greatest sturgeon diversity [50,51]. Their known historical distribution in European fresh and sea waters is the result of colonization during the post-glacial period [33], and they were certainly migrating up the Danube, as evidenced by the artifacts and fish bones discovered in the Neolithic settlements on both river banks of the Danube in the area of the Iron Gates Gorge [52,53].

Compared to other fish species, sturgeons are a distinctive assemblage of fishes with unique morphological characters, unusual genetic characteristics, and particular ecology and behavior. Following their life history, sturgeons show unique adaptations to the large river environments on which all species depend during all or part of their life cycle [48], which include mobility, opportunistic food habits, delayed maturation, high individual fecundity, and longevity [54]. Some of the characters of these fish are those of primitiveness, others of degeneracy, and others of specialization. The snout, ventral mouth, and barbels are the specialized characteristics [12].

Regarding their external appearances and their life histories, sturgeons are unique among other fish groups. Their body kept exoskeleton, covered by bony plates/scutes with rhombic or star-shaped denticles that are organized into five longitudinal rows: one dorsal, two laterals, and two on the ventral side. Lack of scales, the four barbells, a projecting snout, and an inferior mouth forming a protrusible tube are the main particular characteristics of sturgeons [55].

They have a long life cycle, and growth continues with age. It is believed that in large sturgeons, growth is prioritized over reproduction, which does not happen every year. Thereby, they reach large sizes and can occupy the central parts of large rivers, where they swim against currents and move fast. Life spans range from 15 years to more than 100 years, depending on particular species, but nowadays they can hardly reach such ages.

Sturgeons are among the largest fish. For the majority of species, at puberty, the body length is over 120 cm [56].

Sexual maturity is reached late in life (5–30 years of age), and adult males and females do not spawn annually, the spawning periodicity ranging from 2 to 5 years for males and from 2 to 7 years for females, in the case of sturgeons from the Danube River [12] at different ages. The prolificity is high and varies from one species to another, depending on body size and the size of the eggs. It was reported that *Huso huso* females can lay on the ground between 360,000 and 7,700,000 eggs of 3–4 mm diameter and 29.5 mg, and *A. ruthenus* lays between 15,000 and 44,000 eggs of 2–2.8 mm [9,12]. However, of this seemingly myriad of eggs that they lay at once, very few individuals survive to adulthood to lay their own eggs to ensure the perpetuation of the species.

All sturgeon species reproduce in freshwater or water of low salinity [46]. Almost all sturgeon species are diadromous fish that regularly migrate between marine and freshwater habitats [57]. They are gametic migrants; mature adults migrate for the purpose of spawning; their life cycle is adapted according to this reciprocal migration between sea and freshwater. Their form of migratory strategy is the anadrome. Movement into freshwater is necessary for successful spawning. Sexually mature fish migrate seasonally from the sea to freshwaters to spawn and then back to the sea, these seasonal movements into freshwater being essential for successful spawning. In the case of certain species, there are two races with different time periods for spawning migration: winter and spring. Sturgeon spawn in the mainstream or margins of the riverbed with hard substrates (coarse sand, gravel, cobble, stones), the depth of the egg-laying grounds varying from a few meters to 26 m, and the current velocity ranges from 0.5 to 2.2 m s^{-1} in the water column [9,12,56]. The spawning period, the spring, coincides with the season of high-water discharge of the Danube River [10,11,13], when low water temperature and high water velocity favor spawning.

After a certain residence time in the natal river, at a particular age and stage of the life cycle, juveniles migrate to the sea waters, where they feed and grow. When they become sexually mature, they remember where they came from, and, just like their parents and ancestors, they return periodically to the hatching place—the natal fresh waters—to spawn [9]. Therefore the anadromous sturgeons spend most of their lives in the sea, but it is essential for them to migrate into fresh waters for successful spawning. As the speed of the river increases toward its source, the further upstream fish move because the habitats for spawning are better: lower temperature of the water and higher content of dissolved oxygen. So, their return to freshwater is coincident with sexual maturity [58].

The geographical range of sturgeons, their migration behavior, and the required diversity of habitats may be explicated, as for all anadromous fish species, on the basis of the differences in aquatic productivity and the differential availability of food in the sea and freshwaters, which are not constant and change with latitude. The return to nutrient-poor regions for spawning is also of benefit because, usually, freshwater systems have few predators and competitors [59]. Differences in growth opportunities can be noted between species that migrate to the sea and potamodromous species, which have significantly smaller sizes than the anadromous. Other sturgeons are "marginally" anadromous because the adults migrate downstream only to estuarine or nearshore habitats [58], as in the case of *Acipenser nudiventris* from the Danube [12,20].

Migration between two environments that greatly differ has led to the development of a special transitional mechanism between seawater and freshwater, associated with physiological and endocrine changes, particular behavior, and genetic population structure [58]. Returning to freshwater habitats for spawning, even though they are limited in nourishment resources, has the advantage of fewer predators and competitors than in the sea. Migrating sturgeons are able to move against strong fluvial currents; they have an extraordinary swimming capacity and a ground speed of about 50 km/day [60]. In the past, it was reported that moving sturgeons leave furrows at the surface of smooth-flowing water [9,11].

Sturgeons exhibit great individual and ontogenetic variation, and natural hybridization has a high incidence among them, both interspecific and intergeneric, because of the overlap in breeding seasons of different species [9,20,40,41,61]. This phenomenon is even more frequent if their particular spawning river habitats are lost or degraded by dredging, damming, and channelizing [62,63], and different species are forced to use only a few available and suitable sites or when one species is quite rare compared to another species [62]. Recent studies claim that the decline of populations can promote interspecific hybridization as a result of the scarcity of conspecific partners, and the increase of this phenomenon and the presence of fertile interspecific hybrids within natural populations compromise their genetic integrity [64]. Other anadromous species have developed potamodromous forms after becoming landlocked by river dams [65].

2.2. Sturgeon Species in the Danube River and Black Sea Basin and Their Status

Historically, two genera and six species of sturgeons occurred in the Danube River basin and the North-West Black Sea. Although there are no clear characters to diagnose the *Acipenser* genus [9,49] in the study area have been described five species of *Acipenser* and one species of *Huso* genus [9,12,13,16]. Among them, *Acipenser ruthenus* and *Acipenser nudiventris* (*A. glaber*) have been described as exclusively freshwater species (potamodromous species), remain all their lives only in the rivers, and only sometimes, before the Danube floodplain embankment and the drainage of its lakes, they could also enter the lakes or limans during floodings. These were found only exceptionally in maritime waters, near the coasts, and at the mouths of rivers [20]. The other four species are marine anadromous species, mostly inhabiting the sea and only visiting rivers at certain stages of their lives and at certain times, mainly for reproduction. After juveniles migrate to the sea, they need 10–20 years to reach maturity and begin spawning, and, what is important, the spawning does not happen every year [61].

Migration periods vary according to the different species but mainly cover the months from October to July for the spawning upstream migration and from September to November for the downstream one, the returning to sea [9,12,20].

Probably, the first consistent information about the occurrence and distribution of sturgeon fish species in the Danube River, including their biology and ecology descriptions, anatomy observations, and last but not least, the way in which they are captured by fishermen, dates from the beginning of the 18th century [6,66]. Consistent scientific papers were published in the 19th century [30,67].

Thanks to the polymath Grigore Antipa (1867–1944), who performed hydrobiology, ecology, and ichthyology research in the lower Danube and its floodplain, the Danube Delta, and the Black Sea coastal area, towards the end of the first half of the 20th century, was available thorough knowledge of sturgeons: their area of distribution, the bionomic conditions of the environment constituting their habitat, their ecology, and in particular: habitat and residence at different ages, in relation to the variation of the environmental conditions (water salinity, temperature, currents), migration, breeding season, spawning grounds, feed, and wintering [8,9,20]. Based on a thorough knowledge of the biological conditions, Antipa proposed the measures to be taken at that time for the protection of the reproduction and growth of these fish, taking into account that "the abundance of these fish from the mouths of the Danube in former times is beginning to decrease due to the rapacity of man, and statistics show that the large specimens, once caught in considerable numbers, are becoming rarer and that even the general production is considerably decreasing" [20] (p. 3).

Comparative anatomical studies on the two sturgeon genera (*Huso* and *Acipenser*) as well as on the five *Acipenser* species occurring in the Black Sea and Lower Danube were made by Antoniu-Murgoci [68,69].

Due to the various anthropogenic impacts on the Danube River, of which the interruption of the longitudinal river connection between the Lower and Middle Danube River sections by damming is the most serious but also overfishing, the sturgeon species number

has naturally decreased from five to two upstream of the Iron Gates dams [27,33,50,70]. Consequently, the Lower Danube River section has remained the single most important spawning area globally for three of the world's sturgeon species. Nowadays, *A. stellatus*, *A. gueldenstaedtii*, and *Huso huso* have their only remaining spawning areas restricted to the European Union, in the Lower Danube [50], although in the case of *A. gueldenstaedtii*, for over a decade, there were no recorded breeding populations or one-year-old juvenils [71,72].

Acipenser gueldenstaedtii Brandt and Ratzeburg, 1833 (Russian sturgeon) is the largest species of the *Acipenser* genus in the Danube River basin. It is on average 2–4 m long and 80–90 kg in weight [12,16,20,26,73,74].

This species lives permanently in the Black Sea until reaching sexual maturity (8–12 years for males and 13–15 years for females) and then migrates to the Danube for spawning [12]. The spawning period is between the end of April and the middle of June, varying according to the water temperature. However, two periods of migration were reported during the year: the spring migration (February–May), followed by spawning, and the autumn migration (August–November). In autumn, the younger specimens migrate. Thus, these individuals, which used to migrate more than 1200 km upstream, spend the winter in the Danube, during which their gonads mature. Based on about 10,000 specimens caught in a year at the mouths of the Danube, it was determined that the weight of the ovaries before laying eggs represents on average 20% of the body mass [20].

Acipenser gueldenstaedtii, like *Huso huso* and *A. stellatus*, has two races—winter and vernal [12,19,34,74]—and it was reported that it has had great variability in the lower Danube River section [9,12]. Winter races spend the coldest time of the year either in the river itself or in the sea close to the river mouth, whereas vernal fish enter the river at higher temperatures in the spring. Winter races used to ascend even the upper Danube and its large tributaries, where they hibernated in the deep holes of thalweg [20]. In addition, the Russian sturgeon has had a potamodromous/resident form that inhabited the proper only in the Danube [34] and hybridizes with all congeneric species.

In the sea, it lives in coastal waters at 60–70 m depth, its habitat being associated with the *Mytilus galloprovincialis* facies. Adults feed on mollusks, crustaceans, sediment organic matter, and small fish, especially anchovies. During its residence in the Danube, the Russian sturgeon feeds on Ephemeroptera larvae, crustaceans, and fish. The juveniles stay in shallow marine waters for around two years. After that, they migrate to deep waters to feed on mollusks until they reach maturity [9,12,20].

Overfishing and unconventional fishing methods—i.e., bottom trawling—used by the Russian Soviet Republic in international Black Sea waters were invoked as being unethical at the general assembly of the Mediterranean Science Commission in 1933 because they were destroying wintering and feeding habitats and were the main cause of population depletion, both in sexually mature and juvenile populations [20]. Later, the building of the Iron Gates dams led to an ecological catastrophe by cutting off access to spawning grounds. The effects are revealed in the dramatic collapse of the annual catch in the former Yugoslavia, which dropped by almost 90% in 1985, a year after construction of the Iron Gate II dam. In 2005, the catch of Russian sturgeon was only 37 kg in Romania (https://danube-sturgeons.org/sturgeon/russian-sturgeon/ (accessed on 12 April 2023)). However, in the Slovak and Hungarian segments of the Danube River, from 1900 to 1983, only three to four specimens were caught annually, and the last catch of two specimens over 100 cm in length was recorded in Bratislava in 1987 [34].

Russian sturgeon was the most distributed anadromous species in the Danube River. During historical times, it migrated regularly to Pressburg (later Bratislava) and its main distributaries and very rarely as far as Austria, although individual specimens are also documented upstream in Bavaria [27]. In Slovakia, the societal value of Russian sturgeon was established at about EUR 780. Currently, its occurrence is restricted only to the lower reaches of the Danube River, but without breeding populations, it is on the brink of extinction [75] and is officially extinct upstream of Iron Gates Gorge [71]. However,

after 10 years with no detections, a young one-year specimen was registered in the Lower Danube River [72].

Acipenser nudiventris Lovetsky, 1828 (ship sturgeon). In the Danube River basin, the ship sturgeon is known only as a potamodromous resident and has always been rare in the middle and lower reaches of the river [8,9,12,20,67]. At the beginning of the 19th century, it was extremely rare upstream of Komárno and only extremely rarely reached beyond Bratislava. Only a few specimens were caught between Bratislava and Vienna, and the last specimen caught in Vienna was in 1936 [26]. In the Lower Danube, its occurrence was usually until Galați, but occasionally it was entering floodplain lakes during the big floods, the Danube Delta, and Black Sea brackish waters [12,20].

The ship sturgeon is a benthic fish that prefers habitats in hard riverbeds in deep stretches of the Danube River with clear waters and strong currents. Similar to other sturgeons from the Danube, it feeds on moth larvae, mollusks, and crustaceans. It reaches sexual maturity at 12–14 years, breeds once every 2–3 years [12,76], and is considered the most fertile among the sturgeon species (https://danube-sturgeons.org/wp-content/uploads/Ship_Sturgeon_Infographic_danube-sturgeons.org_.jpg (accessed on 12 April 2013)). It was reported that *Acipenser nudiventris* produces hybrids with *Huso huso* and the other native congeners in the Danube [26].

In the middle of the 20th century, the ship sturgeon became increasingly rare along the entire Danube River course, and those few specimens caught were remnants of a very small relict population that was on the edge of extinction [34], a status that was not invalidated later [28].

The disappearance of *A. nudiventris* from the Lower Danube was predicted over four decades ago [25,36,70]. It was declared extinct in Slovakia [34], Romania [77], Austria, and Hungary [70], and functionally extinct in the entire Danube River basin [78,79]. According to the most recent IUCN Red List, *A. nudiventris* is extinct in the Danube River basin and Black Sea and globally critically endangered [80]. The Rioni River is inhabited by the last population of *A. nudiventris* in the Black Sea basin [55].

Acipenser ruthenus Linnaeus, 1758 (sterlet), which is native to the Pontocaspian region and has an Euro-Asian range [81], is the smallest sturgeon species in the Danube River basin that inhabits exclusively freshwater habitats, lives up to 20 years, and grows to some 50 cm in length [82]. It is a rheophile species that lives primarily in the middle Danube and its tributaries. During historical times, the sterlet had ascended the Danube regularly as far as Vienna, was not rare at Linz, and was often gotten at Passsau and in Bavarian waters [24]. It was frequent along the Lower Danube, very rare in the Danube Delta, and was recorded accidentally in the Black Sea coastal waters [9,11,12].

It needs deep and clear waters without high turbidity. Its bentic habitat consists of deep holes in the talveg with a hard substrate of clay, coarse sand, and gravel. Barrage systems from Iron Gates and Gabčíkovo have destroyed suitable spawning grounds and disturbed food habitats [83,84]. In the Middle Danube River section, two types of spawning habitats were described: the riverbed and the fast-flowing sites in the floodplain flooded by rising water [85].

Comparative studies indicate unfavorable conditions for the sterlet population upstream of dams [86], although it was stated that toward the end of the 20th century, the sterlet had made a considerable resurgence in Slovakia and Hungary and was abundant in Serbia [34]. This fact was partially attributed to the improvement of water quality as well as the emigration of individuals from the impoundment of the Iron Gate I dam [34].

Besides, for the Hungarian section of the Danube River, the increase of the sterlet population was also correlated with artificial propagation and restocking activity, but it dropped sharply after the construction of Gabčikovo hydropower station due to the alteration of local spawning sites [85].

As a benthivore fish, its nourishment is based mainly on the insect larvae, and the trophic spectrum of the sterlet differs according to the Danube River section: Trichoptera and Chironomidae, between Baziaș and Belgrad, and Ephemeridae, Chironomidae, Ple-

coptera, and Odonata, between Giurgiu and Hârșova [12]. Additionally, small mollusks of genera Sphaerium, Pisidium, and Viviparus, and representatives of Oligochaeta, Polychaeta, Hirudinea, and other several benthic invertebrates supplement its diet in the Serbian Danube [37], and no less than 46 items constitute the diet of the sterlet population of the Slovakia section of the Danube [27]. However, in terms of feeding habitats, there is spatial segregation of both sexes of *Acipenser ruthenus*. Females feed dominantly on oligochaetes, which are found in riverbed areas with fine sediments and slower currents, while males prefer Trichoptera and Ephemeroptera, which occur in gravel-bottom areas with stronger current velocities.

It hybridizes interspecifically with both local and introduced sturgeon species [87]. The non-native sturgeon species that are occasionally recorded in the Danube can threaten the native sterlet populations not only at the genetic level by hybridization but also at the level of competitors for resources and suitable habitat [29]. The hybrid *Acipenser ruthenus* x *Huso huso*, named Bester, was created for aquaculture purposes for the production of caviar and sturgeon meat [26]. However, it was claimed that in the wild, along the Danube River, *A. ruthenus* reaches sexual maturity at different ages; in the Hungarian-Slovakian section, it is much later (4–5 years for females, 5–7 years for males), and females in this segment of the Danube spawn only once or twice during their lives [27].

Total catch and the catch of sterlet in the lower reaches of the Danube River showed significant decreases after 1990, but it is not only migratory fish species that face, more or less, anthropogenic impacts on the river [55]. Probably one of its advantages over the others is that, although the longitudinal connectivity of the river has been interrupted, it is a potamodromous fish and can adapt to the remaining free sections of the river. According to the IUCN, at the European level, it has been assessed as vulnerable [88].

Acipenser stellatus Pallas, 1771 (stellate sturgeon). The name of this species is related to the distinctive star-shaped bone plates on its body. With its somatic and biological characteristics, *A. stellatus* is considered a transitional species between potamodromous and anadromous sturgeons. It was described as the most euryhaline sturgeon from the Black Sea, withstanding easily at all ages the sudden transition from marine to fresh waters and vice versa [9,20].

Until the beginning of the 20th century, the stellate sturgeon was widely distributed and abundant in the Black Sea, its tributaries, coastal lagoons, and freshwater lakes of the Danube floodplain [12,13,16]. At that time, it was very frequent in the Lower Danube, including Iron Gates Gorge, which was an important spawning place, but very rare in the Middle Danube. Although originally this sturgeon was a long-migratory species, during the 19th century it was rarely noticed above Komárno and only exceptionally reached Austria [67] due to intensive fishing in previous centuries [30,34].

During the 20th century, the stellate sturgeon had a great and important economic and commercial value for the countries bordering the Black Sea and the Lower Danube, both for its meat and caviar [17,19,20]. It continues to be valuable, with *Acipenser stellatus* being the third most important caviar producer after beluga and Russian sturgeon [89].

The main habitat of *A. stellatus* is the neritic domain, up to 70 m depth. Its spawning habitats, a riverbed with rocky, coarse sand, and pebble grounds washed by strong currents, are similar to those of the Russian sterlet, and it has two races with two different migration types [9,12,13]. Both forms spawn in the late spring. In the past, the spawning population of vernal form gathered at the Danube's mouth soon after the thawing of the river. Then, in late March, it starts migrating, following the beluga and Russian sturgeon migrations. The winter form, which is a long migratory form, starts its migration upstream to the river in the late summer. It overwinters in the river, during which the gonads evolve from stage III to stage IV, and, in the following spring, it migrates to spawning habitats [12]. Exceptionally, stellate sturgeon spawns in the sea, on the sandy bars developed in front of the distributary mouths of the Danube where the water is brackish [20].

After hatching, fry start immediately their migration to sea. During the stages of life on the Danube, the stellate sturgeon feeds on larvae of Chironomid, Trichoptera,

Ephemeroptera, and crustaceans. Until the age of two, the juveniles feed and develop in shallow brackish coastal waters, then migrate to the deeper waters and stay there until they reach sexual maturity: males at 6–12 years and females at 8–14 years [50]. At sea, adults feed on crustaceans and mollusks. Based on the stomach content examination of many specimens, it does not feed on fish [20]. Older adults can reach up to 2 m in length and more than 20 kg in weight but they usually have 100–120 cm and 6–8 kg [12].

Before the Iron Gates I dam was built, *A. stellatus* already had a few migrants in the middle stretch of the Danube River, but since 1986, when the Iron Gates II dam was finished, the historical migration route was halved for it, as well as for beluga and Russian sturgeon. Thus, the Lower Danube has remained the only river section with potentially available spawning habitats, but natural reproduction exists on a small scale. It is confirmed by the sporadic spawning events recorded downstream of Iron Gates [90] and the occurrence of young-of-the-year stage specimens [91].

Although upstream of Iron Gates Gorge this species is officially extinct, the results of recent studies showed different genetic diversity of migrating adults and young-of-the-year stage specimens captured downstream of Iron Gates II, which is explained by a genetic input from population units that remained blocked in the Middle Danube River after dam construction, with a possibility for yearlings to drift through the ship locks at Iron Gate dams [92]. Recent studies reveal a high genetic diversity of stellate sturgeon in the Black Sea, but the genetic structure of stellate sturgeon from the north-western Black Sea region indicates a single genetic cluster [93].

According to the IUCN Red List of Threatened Species in 2019, the *Acipenser stellatus* population from the Black Sea basin is listed as critically endangered [94]. A recent study gives evidence of a slight demographic expansion of the north-western Black Sea population of stellate sturgeon after a bottleneck event induced by overfishing and dam construction [93].

Acipenser sturio Linnaeus, 1758 (European sturgeon) is one of the nine anadromous fish species [13] whose autochthony in the Danube has caused controversy among scientists for a long time [95]. It is closely related to *Acipenser oxyrinchus*, both of them being the most ancestral sturgeons and significantly genetically separated from the others [96].

Up until the middle of the 19th century, it was thought to be absent from Black Sea waters and implicitly from the Danube River [67]. Then, it was mentioned as being rare in the Black Sea by [30], which was confirmed by Antipa [97]. At the beginning of the 20th century, its occurrence in the lower reach of the Danube was mentioned for the first time [8]. Afterwards, the catches of young specimens and hybrids with other Danube sturgeon species proved the reproduction of *A. sturio* not only in the Danube [9], but also in the Black Sea, in the brackish and shallow waters in front of the mouths of the Danube, and on the submerged sandbars [20]. *A. sturio* from the Black Sea was observed by Antoniu-Murgoci [98].

Its migration was limited exclusively to the lower Danube [24], up to 400 km upstream from the estuary according to Bușniță [13], while others mention only the Danube Delta as a range [12]. Although a few specimens of Atlantic sturgeon were recorded at the beginning of the 20th century in the middle Danube [26], it was never resident in this stretch of the river [99].

The Atlantic sturgeon was always rare in the Black Sea and the least numerous in comparison with other sturgeons; it did not have great economic importance for Romanian fisheries [20,24], but it was commercially fished in Turkey and Georgia, with an annual yield ranging from 5–7 tons. Consequently, *A. sturio* overfishing had led to the diminution of its population to around 300 specimens at the beginning of the 9th decade of the 20th century in the territorial Black Sea waters of the former Soviet Union and its disappearance from the Kizil Irmak River [74]. However, the last known individual of *A. sturio* in the Black Sea basin was caught by fishermen in 1991 in Georgia, but unfortunately, it could not be rescued by scientists because of the ignorance and contemptuous attitude of the

police authorities [50]. The last scientifically recorded sighting in the Lower Danube was in 1965 [100].

The overall decline of *A. sturio* populations has been observed in their distribution area since the middle of the 19th century [101]. Following several assessments, the possible extinction of the species *Acipenser sturio* from the Black Sea has been suggested for more than three decades [24,26,27,70,74]. Some authors [28] have stated that the extinction of Atlantic sturgeon from the Danube River most likely occurred in 1966–1967 and, at the latest, in 1970. Its extinction was officially reconfirmed by the IUCNN in 2020, according to the last assessment [102].

Huso huso Linnaeus, 1758 (Beluga, great sturgeon) is the largest sturgeon species, the largest freshwater fish, and one of the largest among all current fish on Earth [55]. It was reported that in the 19th century, in the Danube estuary, individuals weighing a thousand kg and being 4–5 m long were caught, from which 100 kg of roe were harvested [20]. Its average length is 215 cm and 200–250 kg. Beluga is a long-lived fish; it can live for even one century [102]. The Danube River was established as a terra typica for *Huso huso* [12]. Historically, this river was the site of one of the largest belugas spawning migrations [103].

During historical times, adults of *Huso huso*, the winter race, migrated upstream for spawning until the Upper Danube River, near Vienna or Linz [8,16,30,63,67], and were among the most abundant of the Danubian anadromous fish [34]. The construction of the Iron Gate dams in 1970 and 1984 blocked upstream access to the middle and upper Danube.

Huso huso is a pelagic-neritic euryhaline sturgeon. In the north-west of the Black Sea, it lives in shelf waters at depths that range between 50 and 100 m. Its occurrence is mainly associated with the *Modiola phaseolina* facies, which is both a feeding and a wintering habitat [9,12,20]. The beluga is a pelagic predator. Adults feed mostly on fish but also on crustaceans and mollusks. In the Danube, juveniles feed mostly on insect larvae and gammaridae, and in the sea, in front of the mouths of the Danube, with mysids and amphipods [12,20,55].

Prior to the construction of the Iron Gate dams (1970–1984) to interrupt upstream access to the middle and upper Danube, beluga migration for spawning occurred in two periods, depending on the race and its gonad development stage [12]. The spring migration used to start very early, even in January, if winter was mild and there was no ice on the Danube. Older adults, with gonads in stage IV, were migrating first. In the late summer had migrated individuals of winter race, whose gonads are in stage III. Their maturation took place in the river during the wintering season. Males reach sexual maturity at 10–16 years, females at 14–20 years, and they carry eggs only once every five to seven years [55]. It is estimated that beluga sturgeon sexually mature at a size of 160 to 200 cm [95]. Depending on age, a female can produce between 360,000 and 7,700,000 eggs [12]. That is the black caviar—the product that makes it the most coveted and vulnerable fish! The suitable spawning grounds are deep holes (8–20 m depth) in the main riverbed with a hard substrate covered with gravel and coarse sand and a moderate to swift current. After spawning, from June to September, adults return to the sea, depending on how far apart the breeding sites were. Since migration distances of the beluga spring form are much shorter, this means that its occurrence is limited to the Lower Danube, whereas in the past, over long distances, up to the Upper Danube, the winter form migrated. The maximum spawning migration is in the spring. Reproduction takes place during the spring for all migrant specimens [9,12].

The traditional spawning habitats were located in the middle Danube, including Iron Gates Gorge [34]. In the lower Danube, spawning habitats were described in at least three places [11,12,57].

Studies in the last decades have revealed that *Huso huso* is able to spawn in the lower reaches of the river, upstream of kilometers 300 until the Iron Gates II dam, and also that this river dam-free sector of the Danube provides suitable habitats for juvenile rearing [25,103]. Thirteen spawning grounds of beluga were identified between river km 755 and river km 840, located at a depth of 9–22 m and consisting of gravel and coarse sand substrate [104].

Their occurrence is associated with the vicinity of the fluvial islands, but belugas also use the rocky substrate of the Dobrogea side of the Danube [25].

A potential spawning site on a rocky substrate was found at river km 100 [105]. However, based on the estimation of the number of eggs laid at the surveyed sites, it was concluded that the breeding habitats of the beluga sturgeon are not fully utilized due to the insufficient number of breeding individuals that reach the spawning sites [104].

Monitoring of downstream migration of young-of-the-year *Huso huso* in the last two decades, research has revealed that a growing number of females have had access to spawning grounds in the lower river and produced offspring [60,106,107].

Swimming depth behavior during migration in the remaining available section of the Lower Danube River was recently described [74]. It naturally hybridizes with *Acipenser* species. Hybrids with *A. nudiventris*, *A. gueldenstaedtii*, and *A. stellatus* were created in Russia for aquaculture [95].

Due to its high economic value, *Huso huso* was the first species of sturgeon that was overexploited until depletion in the upper and middle Danube started in the Middle Ages [23,26]. The cause of the significant decline of the beluga population, which was noticeable due to a drastic decrease in catches, has been explained since the middle of the 19th century: the ruthless exploitation of the spawning stocks [67]. The intensity of beluga fishing has far exceeded the potential for growth through natural reproduction. Consequently, in the early modern period, the beluga had almost disappeared from the Danube upstream of Vienna, and in the first years of the 18th century, in the upper part of the Danube low-lying zone, *Huso huso* specimens were only caught by chance [63]. The last beluga record in the Slovakian-Hungarian stretch of the Danube was a female specimen in 1925, at river km 1957 [34].

The last two known house catches upstream of the Iron Gates power plants were in 1972 and 1987, the latter individual presumably crossing both dams via the ship locks [99].

Huso huso is extinct from the Danube upstream of Iron Gates Dams [26,82] and its population has decreased continuously in the Lower Danube River since the last half of the 20th century [19]. According to the last IUCN assessment, the conservation status of *Huso huso* is critically endangered in the Danube Delta basin and its entire geographical range [108]. Compared to historical population sizes, what has survived in the lower Danube is only a residual population [19,95].

3. The Historical Decline of Sturgeon Population in the Danube River and Black Sea Basin—Why and When It Started

For thousands of years, every year, between certain periods of time, large numbers of sexually mature sturgeons have migrated unhindered more than 2000 km from Black Sea coastal waters upward to the Danube River and its main tributaries for spawning and back to sea. Based on existing literature on sturgeon, migration periods vary according to the different species but mainly cover the months from October to July for the spawning upstream migration and from September to November for the downstream one, the one returning to sea.

Archaeological records prove that in the Danube River basin, human beings have interacted with sturgeons since the Middle Stone Age. The sturgeon fish and their migration played a major role in the symbolism of the Iron Gates Mesolithic culture, especially the belugas annual spring return, which must have been an impressive event, taking into account the size and weight of this fish. It was stated that, at least initially, they symbolized life for that ancient human society, and perhaps this fish, by its perpetual return, was more important in ideology than in the main survival strategies. Eloquent evidence is provided by the carved sandstone figures of human/fishlike beings from Lepenski Vir that reveal the sturgeon's basic physical traits in a realistic representation [52]. Because these sculptures are associated with graves, they are interpreted as various stages of the metamorphosis of deceased adults into fish [109]. Later, large amounts of archaeological remains from sturgeons (bony plates) and various stone tools were found on both sides of

Iron Gates Gorge, and isotopic evidence supports the idea that sturgeons, along with other species, had a prominent role in the subsistence strategies of humans at the beginning of the Holocene [53].

In addition, there are archeozoological evidences from antiquity that prove that sturgeons migrated beyond the Iron Gates Gorge into sections of the Danube located in present-day Austria and Bavaria [22], and their fishing and dietary roles for human society in the area have been documented since at least 3500 BC [23].

On the western coast of the Black Sea and at the Danube River mouths, the sturgeons have played an important role in the fishery since ancient times. It was mentioned by Herodotus that people of the Greek polis Histria, settled by Milesians in the 7th century BC, fished and traded sturgeons [110].

Documentary mention of sturgeons in the Danube and Black Sea came also to the Greek geographer Strabo (c.64 BC—c. 24 AD) in his paper Geographica, Book VII: "There are also fish which are taken in the ice by means of a round net called a gangama, and especially a kind of sturgeon called antacæus, nearly the size of a dolphin [111]".

Although there is no information about the number of catches in antiquity, they were an important food resource. The Roman legions stationed along the Danube depended at times on beluga-trapping for food [95]. The intensive fishing of sturgeons, particularly in the Upper and Middle Danube sections, started during the Middle Ages. Although sturgeon could be found throughout the Danube at different times of the year, the geomorphological diversity of the river course created distinct opportunities for sturgeon fishing in some locations. The wood fences were used for fishing, which was an efficient method [30]. Later, they were harpooned and caught with large metal hooks [11]. In 1537, around 1000 belugas were said to have been caught on a catch fence, and 140 belugas were captured within 13 days at the fence in Kolárovo, Slovakia [95]. Another documented place was the Iron Gates Gorge, which was a spawning place when traps and iron baskets were used [19]. In the Iron Gates Gorge, where the river width was only 170 m before damming, they were increasingly vulnerable to human predation. The down-stream exit of the Iron Gates gorge may also have served as a natural trap where upward migrating sturgeons, slowed by rapids, could be relatively easily caught in prehistoric times [23].

By 1690, it was mentioned that "50–100 sturgeons were caught and butchered daily" at the Island Ada-Kaleh (now submerged), downstream from Orştown, now in Romania [66]. Live sturgeons were towed upstream by boat to markets in the capital cities of Hungary and Austria in the 18th century [95].

It is difficult to estimate how much fish was caught, but based on written historical records, it can be indirectly stated without the risk of making a mistake that the ruthless exploitation of the spawning stocks began in the Middle Ages, especially in the Lower and Middle Danube [22,23]. Fish sold annually in and around the city of Vienna during the 1795–1823 period ranged between 5 and 45 tons [95]. A French consul in Moldavia reported in 1762 that about 25,000 belugas were caught annually in the Chilia branch of the Danube River [112].

How big were catched sturgeons? According to documented records, one fifth of all beluga whales were 4–6 m in length [33]. For the Lower Danube, Antipa [97] refers to an extreme record in 1890 when a beluga sturgeon weighing 882 kg was caught in the mouth of the Sfântu Gheorghe branch of the Danube.

Nowadays, it is unlikely that members of depleted populations of sturgeons will achieve the historically reported maximum sizes of individuals; such specimens have likely become extinct. In fact, it was estimated that since 1800, the body weight of beluga whales has decreased, with an annual average of 1.84 kg [113]. During the last decade, not only the size but also the structure of the sturgeon population changed dramatically. Individuals are smaller and younger than in the past.

Without a doubt, sturgeons were and are the most valuable fish, both for their highly palatable flesh and eggs, but their economic value has increased significantly since the second half of the 20th century due to increasing demand on the caviar market, a particularly

precious commodity. If in the fourth decade of the 20th century fisheries yielded more than 700 tons of fish yearly, during the sixth and seventh decades of the 20th century annual sturgeon catches from all the riparian countries of the Lower Danube, according to the official statistics, ranged between 300 and 80 tons, and at the beginning of the 21st century, official records were of 25–30 tons per year [70]. However, at the end of the 20th century, it was revealed that the official catch records are far from reality; they represent no more than ten percent of the real catch size. Other sources say that 884 beluga specimens (106 tons) were harvested from the lower Danube in 1997 [95].

One of the indirect causes of the declining sturgeon population on the Lower Danube may be related to the change of political regime in all countries bordering the river downstream of the Iron Gates Dam. The transition from the communist economic system to the market economy and private ownership favored a great increase in the number of private fishermen, particularly in Romania, during the 1990s [114]. Thus, the lack of legislation to regulate yield control stimulated illegal fishing and overfishing.

Apart from overfishing, the second major cause of negative impacts on sturgeon populations has been the incessant habitat degradation caused by the sum of anthropogenic activities along the river's course and its main tributaries.

Destruction of spawning grounds was caused by deforestation and intensive agricultural development, which led to changes in river flow, an increase in water turbidity, and fine sediment deposits on the riverbed, which altered the sand, gravel, and rock bottom of sturgeon spawning grounds.

Dams have massive impacts on fish, particularly migratory species [83]. There are 63 dams/reservoirs along the Danube River and its watershed, of which 31 are hydropower dams [26]. As it was already mentioned, the Iron Gates dams have brutally interrupted the longitudinal connection between the Lower and Middle Danube and have shortened sturgeon migration by over 1000 km. However, not only sturgeons are directly affected by the dams but also other migratory and non-migratory fish species and biota, including the catadromous *Alosa immaculata*, which has vulnerable status according to the IUCN Red List [55] and is protected at the European level under the Habitats Directive [50,115].

The extraction of sand and gravel has reduced benthic biomass, which is the main food source for sturgeons [19].

Water pollution by oil, heavy metals, pesticides, and high loads of nitrogen and phosphorus both in the Danube and coastal waters have had negative impacts [19,36]. Because sturgeons are benthic, long-lived fish, they are sensitive to pollution, particularly heavy metals [116]. These pollutants may cause organ dysfunctions, especially in the gonads, which leads to reduced fertility and has a negative impact on both individuals and populations [117]. Due to the high nutrient loads of coastal waters, algal blooms and hypoxia episodes occurred periodically (1950–1992) in the 10–40 m deep coastal waters, which represent the main habitat for anadromous sturgeons. Consequently, a massive amount of biologic mass was lost, including mollusks and other benthic food organisms from sturgeons. In addition, the invasive species *Mnemiopsis leidyi* changed the faunal structure and distribution of invertebrate fauna and indirectly impacted sturgeons [19].

All these fish species, members of the family Acipenseridae, which was able to adapt and evolve over 200 million years and survived previous mass extinctions, are threatened by the Anthropocene extinctions of the past 100–200 years. Their extirpation from the Danube River basin has occurred gradually since the 16th century, from upstream to downstream of the river.

All anthropogenic direct drivers that are associated with the current Anthropocene mass extinction [118,119]—habitat modification, fragmentation and destruction, overexploitation, pollution, climate change, and the spread of invasive species—are also valid for sturgeons.

4. Instruments of Conservation Mechanisms

The conservation of sturgeon species and sturgeon habitats represents the objective of a national and international legal framework implemented through different institutions within some programs.

4.1. Legislative Framework

4.1.1. Conventions and International Treaties

The most important international conventions having as objectives the conservation of sturgeon species and their habitats are the Danube River Protection Convention (DRPC), the Bern Convention, the Bonn Convention [120], the Ramsar Convention, and CITES [121].

The DRPC forms the overall legal instrument for cooperation on transboundary water management in the Danube River Basin. The Convention was signed on 29 June 1994, in Sofia (Bulgaria) and came into force in 1998. It aims to ensure that surface waters and groundwater within the Danube River Basin are managed and used sustainably and equitably [122].

The Bern Convention, or Conservation of European Wildlife and Natural Habitats, founded in 1979, was the first international treaty to protect both species and habitats and to bring countries together to decide how to act on nature conservation.

The Ramsar Convention, or Convention on Wetlands, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

CITES, or the Convention on International Trade in Endangered Species of Wild Fauna and Flora, is an international agreement between governments. The aim of this convention is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species.

4.1.2. European Legislation—Directives

For the protection of the majority of sturgeon species, it is necessary to preserve three types of habitats: coastal habitats, shallow freshwater habitats, and watercourses. All three types of habitats and all species of the family Acipenseridae are present in the annexes of the Habitats Directive 92/43/EEC [123]. In accordance with Article 17 of the Habitats Directive, the EU member states present in the Danube basin (Germany, Austria, the Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Bulgaria, and Romania) have the obligation to report every 6 years on the conservation status of the species and habitats listed in the directive's annex. The conservation status of the three habitat types and the populations of the sturgeon species are evaluated according to pressures and threats. The pressures exerted on the species and habitats of sturgeons in the Danube basin and Black Sea are the following: flood risk management (construction of embankments, breakwaters, and seawalls), hydroelectric power use, navigation, water level oscillations induced by effluents, drinking water supply, pollution (organic with petroleum products, nutrient and pesticide diffuse discharge from agriculture land, substances pointy discharge from industry, hydro-geomorphological alterations by erosion, invasive species, climate change, etc.) [122]. Most of the pressures and threats change the water quality for the worse and modify the shape and structure of the basins of water bodies. The EU Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy) provides at the European level conservation measures for both water quality and aquatic habitats.

4.1.3. National Legislation for EU States

Germany. All EC directives have been transposed in Baden-Württemberg and Bavaria into the national law system. The transposition was completed through updated versions of the Water Resources Act (WHG—18 June 2002), the Bavarian Water Act (BayWG—1 August 2003), the Water Act for Baden-Wuerttemberg (WG—22 December 2003), and the implementation of appropriate ordinances as to the implementation of Annex II and V

WFD. Agricultural discharges The Nitrates Directive 91/676/EEC is transposed into the national law system [124].

Austria. The Habitats, Water Framework, and Nutrients Directives were transposed into national legislation and partially implemented. The Water Rights Act of 1959 constitutes a comprehensive legal framework for the evaluation of the most different living conditions relevant from the point of view of water management.

Czech Republic. The European legislation was transposed and partially implemented, and the water quality at the national level is protected by Water Act 254/2001.

Slovakia—the European legislation was transposed and partially implemented, and the water quality at the national level is protected by Act No. 369/1990 on Municipalities, Act No. 442/2002 on Public Water Supply and Sewage Systems, as amended, Act No. 250/2012 on Regulation in Network Industries, as amended, and Decree No. 21/2017 establishing price regulation of production, distribution, and supply of drinking water using the public water supply system and drainage and treatment of sewage water through the public sewage system.

Hungary. The European legislation was transposed and partially implemented, and the water quality at the national level is protected by Act No. LVII of 1995 on water management.

Slovenia—the European Directives were transposed into national laws and partially implemented; the water quality at the national level is protected by the Water Act (Official Gazette RS, No. 67/02, 2/04—ZZdrI-A, 41/04—ZVO-1, 57/08, 57/12, 100/13, 40/14, 56/15, and 65/20).

Croatia. The European Directives were transposed into national legislation and partially implemented, based on Article 89 of the Constitution of the Republic of Croatia; it was an adopted law on water services no. 1286/2019.

Bulgaria. The European legislation was transposed and partially implemented; the water quality at the national level is protected by Water Law 67/1999, which was annually amended until 2016. Romania—the European legislation was transposed into national legislation and implemented; the water quality at the national level is protected by Water Law No. 107/1996, ORDER No. 85/662/2021 on measures to restore and conserve sturgeon populations in natural fish habitats, and Emergency Ordinance No. 202/2002 regarding the integrated management of the coastal zone. Although the sturgeon migration from the Black Sea to the Danube is influenced by the activities of three countries in the Danube Basin (Ukraine, Bulgaria, and Romania), Romania is the only state that has taken extreme measures to preserve sturgeons by banning fishing for a period of 20 years (two 10-year intervals).

4.1.4. National Legislation for Non-EU Member States

Bosnia-Herzegovina, Serbia and Montenegro, Moldova, and Ukraine are non-EU states; within them, the provisions of the three European Directives are not applied. These states, being signatories to the DRPC, have transposed parts of the provisions of this convention into their national legislation.

4.2. Institutions

The most important institutions involved in the conservation of sturgeon species and sturgeon habitats are the Danube Commission (DC), International Commission for the Protection of the Danube River (ICPDR), International Association for Danube Research (IAD), International Union for Conservation of Nature (IUCN), European Commission (EC)—European Environment Agency (EEA), National Ministries of Environment and Agriculture of each state, WWF (World Wildlife Fund), and WSCS (World Sturgeon Conservation Society).

The Danube Commission is an international intergovernmental organization based in Budapest that was created in accordance with the provisions of the Danube Navigation Regime Convention, signed on 18 August 1948, in Belgrade. The Convention on the

Navigation Regime on the Danube is the instrument of international law that regulates navigation on the Danube and guarantees the free movement of ships on this important European river, in accordance with the interests and sovereign rights of the member states. The member states of the Danube Commission are: Austria, Bulgaria, Croatia, the Russian Federation, Germany, the Republic of Moldova, Romania, Serbia, Slovakia, Ukraine, and Hungary. The official languages of the Danube Commission are German, Russian, and French.

ICPDR is the commission that ensures the sustainable and equitable use of waters in the Danube River Basin. The work of the ICPDR is based on the Danube River Protection Convention (DRPC), the major legal instrument for cooperation and transboundary water management in the Danube River Basin [122]. ICPDR has 16 fields of activity (Agriculture, Dams and Structures, Droughts, Ecosystems, Floods, Groundwater, Human Impacts, Industry, Invasive Species, Municipalities, Nature Protection, Navigation, Plants and Animals, Water Pollution, Water Quality, Wetlands), of which four are explicitly related to nature conservation [122].

The Danube Commission, together with the Sava River Basin Commission and the International Commission for the Protection of the Danube River, supported by the European Commission and also national authorities and NGOs, are joining their efforts on the protection of the riverine environment and improvement of the sustainable development of inland navigation in the Danube River Basin. The reunion is part of the annual follow-up meetings of the Joint Statement, which are constantly organized by the three organizations.

IAD is a scientific association that promotes and coordinates activities in the fields of limnology, water management, water protection, and sustainable development in the Danube River basin. This association provides the scientific basis for management decisions in the Danube Basin.

IUCN is a union of members of governmental and civil society organizations working together to promote sustainable development and create a just world that values and conserves nature. This union, with over 1400 members from over 160 countries, has developed red lists of species with high conservation value; on these lists are all the fish species belonging to the family Acipenseridae.

The EC-EEA provides environmental information to policymakers and the public from the member states of the European Union. The EEA receives, integrates, and evaluates the member states' reports on the state of conservation of species and habitats of community interest, including sturgeon species and their habitats. It establishes the priorities regarding the conservation measures and directs the funds necessary for the implementation of the measures.

National Ministries of Environment and Agriculture in each state, in accordance with the signed Conventions, are responsible for the preparation and implementation of the strategy and national action plans for the conservation of species and habitats of sturgeons.

WWF is a non-governmental organization majorly involved in the conservation of the Danube corridor and the species and habitats of sturgeons, being a partner in projects implemented by ICPDR and IAD.

WSCS acts as an international forum of scientific discussion, focusing on information and data related to the biology, ethology, ecology, and economy of sturgeon species around the globe, as well as sturgeon habitat conservation.

4.3. Programs

European Commission, financed by different programs such as the Danube Transnational Program and WE PASS, two research programs in recent years: MEASURES (Managing and restoring aquatic EcologicAl corridors for migratory fiSh species in the danUbe RivEr baSin) and WE PASS—Facilitating Fish Migration and Conservation at the Iron Gates. Both projects were implemented by international consortia, in which ICPDR played a major role.

IAD has developed international projects and studies funded by SEE-TCP, LIFE+, and Danubeparks, such as Danube-ReConnect and LinkStur. A feasibility study was carried out on the passage corridors for the commissioning of the Iron Gate dams for sturgeon and other migratory fish species. In addition, the IAD task force for Danube sturgeons, which includes all relevant stakeholders, was established to reactivate the implementation of the PAS and to find means to coordinate and promote the conservation of native sturgeon species in the Danube Basin (DRB) and the Black Sea adjacency. The application forms for the "Sturgeon 2020 Program" project proposed for the further implementation of the PAS were made.

Through its project, IAD provides continuous and proactive scientific support to ICPDR, EUSDR (EU Strategy for the Danube Region), TRAFFIC (Wildlife Trade Monitoring Network), CITES, and FAO (Food and Agriculture Organization of the United Nations) to promote sturgeon conservation policies implemented by management plans and legislation.

In November 2018, the Standing Committee of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) adopted the Pan-European Action Plan for Sturgeons [39] and recommended its implementation under the Habitats Directive in May 2019. This plan is for all native European sturgeon species and sets the framework to conserve the last surviving sturgeon populations, both in-situ and ex-situ according to particular circumstances, to protect and restore their habitats and migration routes, to reintroduce the species to a number of key rivers, and last but not least, to prevent illegal fishing and trade [88]. The plan is intended to serve as a guiding framework until 2029. For the Danube River, a feasibility study for fish passage at Iron Gate is planned.

The programs implemented by the institutions presented above foresee activities to reduce the human impact (pressures and threats) in order to improve the state of conservation; reconstruction of some damaged habitats; and information and education of the stakeholders.

5. Conclusions

Sturgeons represent ecologically, economically, and culturally important species. *Acipenser sturio* was always the rarest of the six species, entering the Danube Estuary only occasionally for spawning. All other species were either common or abundant in the Middle and Lower Danube Rivers, especially during spawning season.

In the Danube River catchment as well as in the rest of Europe, sturgeons have been heavily fished commercially since the Middle Ages in the Upper and Middle Danube Rivers. Accordingly, the population of each migrating species decreased dramatically toward the middle of the 19th century. The stocks of the anadromous species, *A. gueldenstaedtii*, *A. stellatus*, and *H. huso*, drastically decreased in the Lower Danube River at the end of the 20th century. The interruption of spawning migration to the main spawning habitats from the Middle Danube River by Iron Gates dams was catastrophic, especially for the winter forms of anadromous sturgeons. Most probably, the majority of the breeding populations with their genetic diversity were decimated in the years immediately following the construction of the two Iron Gates dams, which is proven by catch records. If no fishways are created at these dams, they will remain a serious hindrance to restoration efforts for the sturgeon population.

Destruction, degradation, and alterations of different habitats, in the sea and in freshwaters, by dredging, navigation, increasing water use, and water pollution with nutrients and heavy metals have had significant impacts on sturgeons and have remained important threats to them. The negative impact has been intensified by illegal fishing after all bordering countries agreed on a fishing ban in 2006.

Action plans to protect and recover the sturgeon population were established in the last two decades, including restoking actions with cultured juveniles. The international/European efforts are led by the International Association for Danube Research and the World-Wide Fund for Nature. Action plans are ambitious, but reconstruction of the species distribution in the catchment area of the Danube is only possible to a very limited

extent. Both in-situ and ex-situ conservation programs are planned. Because sturgeons display homing behavior and anadromous species developed two migration forms with differences in spawning seasonality, conservation programs should be developed to avoid genetic homogenization of remained individuals of populations that cannot migrate to their natal spawning area because of dams. Cultured exotic sturgeon species that have escaped into the wild are also an important threat to the autochthonous remnant population, taking into account their availability for hybridization.

In spite of the ambitious policies of governments and conservation projects led by nongovernmental organizations, the results are not only modest, but the situation has worsened in the last decade. According to the latest IUCN comprehensive assessment, which was released in 2022, of all six sturgeon species that historically were recorded in the Danube River Basin and north-west Black Sea coastal waters, two are extinct (*A. sturio* and *Acipenser nudiventris*), *Acipenser rhutenus* has been reclassified from vulnerable to endangered, and the others are critically endangered. Because sturgeons have long generation intervals and irregular spawning patterns, the recovery of stocks needs long time periods.

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