Past and Future of Sturgeon Species (Acipenseridae) in Western Balkans: Case for Permanent Conservation or Sustainable Management

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Abstract Sturgeon species in Western Balkans are mainly occupying the Danube River basin, which represents one of the centers for sturgeon diversity. Although there are numerous negative anthropogenic impacts (habitat fragmentation, pollution, fishery pressure) on sturgeons, constructions of hydropower dams in the Iron Gate area severely decreased their natural spawning habitats and only sterlets have a viable population upstream from Iron Gate 2 dam. Review of the status and population trends based on available statistics, pollution impact, composition and change in their diet, the impact of invasive species, as well as restocking and ex situ conservation programs will be presented. Assessment of legislation and sturgeon protection projects and their impact on wild sturgeon populations will be discussed.

Keywords *Acipenser* sp. · *Huso huso* · Parasites · Aquaculture · Endangered species · Protection

1 Introduction

With fossils dating from about 300 million years ago, sturgeons can be considered "living fossils," undergoing little morphological change and with many biological features of ancient fishes (Carmona et al. 2009). Essentially, they maintained their

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present traits (homing behavior, longevity, late maturation, and low fecundity) for more than 200 million years, establishing regular and abundant populations through the Northern Hemisphere. They survived glaciations and mass extinction events, while adapting to different living conditions from cold environment of Siberia and North America to warm Mediterranean waters (Hernando et al. 2009; Jarić et al. 2011a). Since all sturgeons are migratory (anadromous or potamodromous) and spawn in freshwater, they are particularly vulnerable and extremely susceptible to anthropogenic impact, such as fisheries, habitat pollution, and alteration of their migratory routes (Freidrich et al. 2018). This was the main reason for development of numerous strategies for sturgeons conservation in wild and for their aquaculture, not only for market demand (caviar and meat), but also to raise adequate specimens for conservation and repopulation of their natural habitats. Recovery of the wild sturgeons requires a sound knowledge of their taxonomy, biology, and biogeographical distribution.

Sturgeons can be easily identified by elongated snout with the four barbels in front of the ventrally located mouth, five rows of bony scutes on a body, a single dorsal fin situated near a heterocercal tail, no branchiostegal rays and a largely cartilaginous endoskeleton (Helfman et al. 2009). They feed (mostly) on benthic invertebrates, although larger individuals can feed on fishes due to specific morphological jaw suspension. With mobile hyoid arch and the independence of the jaws from neurocranium, sturgeons are able quickly to protrude jaws from the neurocranium (Carroll and Wainwright 2003) and efficiently feed on its pray. They do not rely on vision in pray detection, but rather on touch, chemoreception, and possibly electrolocation through rostral ampullary organs (Helfman et al. 2009). With sturgeons being particularly long-lived fishes, and having rare natural predators beyond the juvenile stage, their natural mortality rates of adults were historically low. With their sexual maturity attaining slowly, and their high fecundity (ovaries may account for 25% of female body mass) and long period of spawning intervals for females (every 3–5 years or longer), sturgeons are susceptible to overexploitation by humans. All 27 sturgeons species, belonging to the family Acipenseridae and grouped in four genera (*Acipenser*, *Huso*, *Scaphirhynchus*, and *Pseudoscaphirhyncus*), are listed on the IUCN Red List of Threatened Species. With 85% of sturgeon at risk of extinction, this group of fishes is regarded as most threatened animals group in the world.

With many factors influencing the decline of sturgeons populations, such as unsustainable exploitation, blocking of migration routes, destruction of habitats, water pollution, loss of genetic integrity of native species, and change in hydrological regime, question should be addressed about measures which supposed to stop rapid disappearance of this group of fishes. Due to demand for their caviar and meat, fishing pressure was affecting populations for over the 150 years. Ristić (1963a) reported significant decrease of sturgeons catch in Low Danube Section even before construction of Iron Gate dams. Although legal, fishing was unsustainable. Mrdak (2009) reported dramatic decrease of sturgeon catch in Skadar Lake drainage, from 1947–1966 period (two tones) to 1967–1976 (no catch), due to construction of stationary fish weir. This was governmentally constructed and controlled fish weir (from 1960 until the late 1980s), in order to harvest fish migrating from Adriatic Sea to Lake Skadar, via Bojana/Buna River (Mrdak 2009). With governments passing legislations on protection and implementing complete fish ban on sturgeons catch, the illegal catch (and caviar trade) is still occurring and continuously providing negative effect to any restoration actions. According to Jahrl et al. (2021), 1/3 of sturgeon caviar and meat products in Low Danube countries were sold illegally. Additionally, 19% of all samples came from wild sturgeon, which makes their origin and trade illegal. Habitat alteration (and subsequent loss) is due to construction of hydropower infrastructure, and enforcement of measures for navigation and flood protection. On the Volga River, after the construction of dams, sturgeons lose 80–85% of history spawning grounds, with beluga spawning grounds reduced almost 100% (Secor et al. 2000). Dams construction in Iron Gate area of the Danube River influenced variation in composition of bottom fauna (Janković et al. 1994; Djikanovic et al. 2015). Even in situation where there was no dam obstruction (e.g., the Ural River), sturgeons lost 50% of spawning grounds due to pollution and sedimentation (Secor et al. 2000). According to Freidrich et al. (2018), loss of genetic diversity is caused either by careless selection of breeders in stocking or ex situ conservation programs or by demographic bottleneck in natural populations. Danger of misidentification was exposed in 2016, when state authority approved stocking of Mura and Sava River with sterlet (15 and 93 specimens were released, respectfully), without previous survey, subsequently only to discovery that specimens belong to nonindigenous Siberian sturgeon (Govedič and Friedrich 2018). Once exotic sturgeon species, genotypes, or hybrids are introduced (deliberately or unintentionally), it can lead to loss of genetic characteristics of wild species, compromises its adaptation to a given set of habitat features and diminishes its population fitness by outbreeding depression (Freidrich et al. 2018).

Although the term “Western Balkans” is political, mostly used to describe area of former SFR Yugoslavia and Republic of Albania, hydrologically it represents area of Balkan peninsula (mainly) related to Black and Adriatic Sea drainage. In this contest, historically area of Western Balkan was inhabited by seven sturgeon species, sterlet (*Acipenser ruthenus*), Russian sturgeon (*Acipenser gueldenstaedtii*), Adriatic sturgeon (*Acipenser naccarii*), ship sturgeon (*Acipenser nudiventris*), stellate sturgeon (*Acipenser stellatus*), European Atlantic sturgeon (*Acipenser sturio*), and Beluga (*Huso huso*). With the Danube River Basin being biggest contributor to the Black Sea drainage in the Balkans, most of the sturgeons were inhabiting this river and its tributaries, with only Adriatic sturgeon and European Atlantic sturgeon entering rivers of Adriatic Sea drainage. However, after construction of Iron Gates (IG) Dam 1 and 2 (in 1970 and 1984, respectively) on the Danube River, sturgeons spawning migratory routes were blocked. Although the Danube River Basin experienced rapid decrease in sturgeons catch by mid-nineteenth century (Lenhardt et al. 2008), significant decline of sturgeons number was after constructions of IG dams and increase of intensive fishing pressure. Adriatic sturgeon and European Atlantic sturgeon experienced similar trend, with increased fishing pressure, pollution, and (in some cases) regulation/alteration to Adriatic Sea drainage rivers. Rare sturgeons research through the region of West Balkans are not sufficient to give better insight into real condition of wild populations.

2 Western Balkans Sturgeons Species

One of the most distinguishing differences between genus Huso and Acipenser is that former genus has a large mouth shaped as a crescent moon, occupying almost the entire width of the lower surface of the head, while latter genus have a suitably large transversal mouth, occupying only part of the lower surface of the head (Maximov et al. 2014).

2.1 Acipenser Ruthenus Linnaeus, 1758 (eng. sterlet, rus. стерлядь, srp. ке▯ига, hrv. kečiga, slv. kečiga)

2.1.1 Distribution (Past and Present) in Europe and Western Balkans

In Europe occupy rivers in the drainages of Black, Caspean, Azov, Kara, and White Seas, while in Siberia occupy rivers in drainages of Ob and Yenisei River (Sokolov and Berdicheskii 1989; Freidrich et al. 2018). In the Danube and its tributaries: Sava, Alt, Tisza, Drava, Mura, Vah, Morava, Inn, Isar; Dnjeper, Dniester, Don, Kuban, and their main tributaries in the Black Sea range (Freidrich et al. 2018). In the Danube, regularly occurred up to Vienna, frequently to Linz, Passau, Regensburg, and even Ulm, with large autochthonous population between Passau and Regensburg (Hensel and Holčik 1997). In Western Balakans, abundant populations through the range, in the Danube, Sava, Kupa, Drava, and Mura River (Hensel and Holčik 1997; Govedič and Friedrich 2018).

Presently (Fig. 1), one small isolated population with limited reproduction occurs in the fragmented section of the Upper Danube (Austria), with populations in Middle Danube experiencing recovery in Slovakia and Hungary (Freidrich 2018; Freidrich et al. 2018). In Western Balkans, most abundant populations are near Smederevo, Belgrade, and Zemun, with viable population in Tisza, while populations in upper section of Danube in Serbia experienced severe decline (Cvijanović et al. 2017). Present in Sava, Drava, and Mura River in Croatia (Mrakovčić et al. 2006), while sporadic occurrence in Drava River (Slovenia) could be attributed to downstream migrations from Austria and its reintroduction program (Govedič and Friedrich 2018).

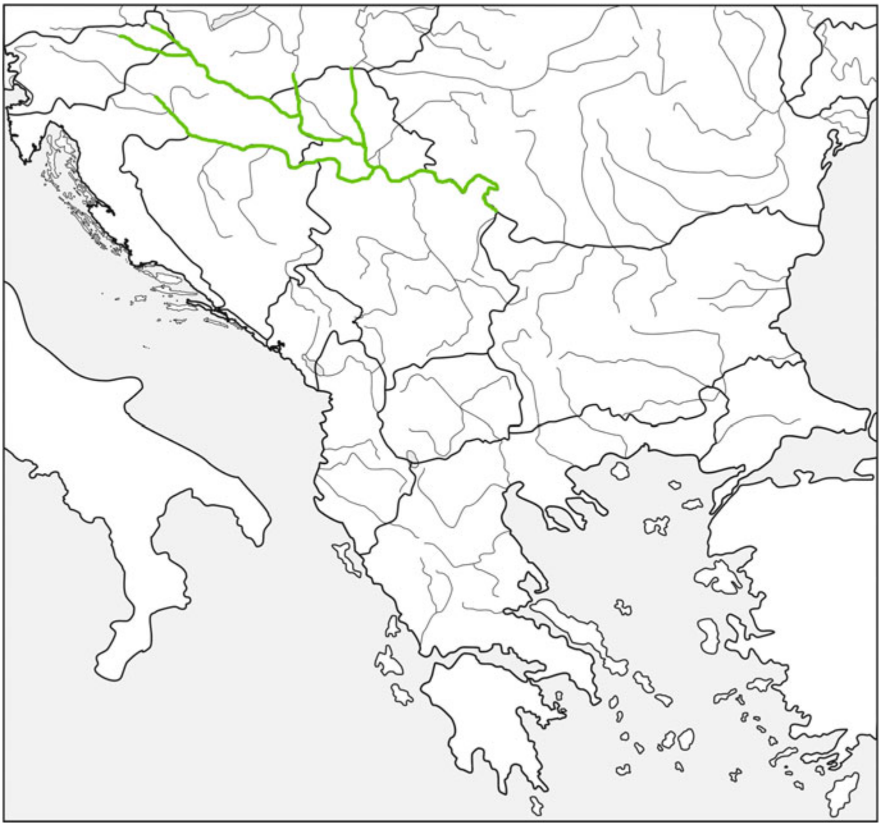

Fig. 1 Present distribution of *Acipenser ruthenus* in Western Balkans

2.1.2 Species Description, Biology, and Habitat

In dorsal row 12–17 scutes, with first dorsal scute not fused with head. Number of lateral scutes is 56–71, while there are 10–19 scutes in ventral row. Lower lip interrupted in middle, with four long fimbriate barbels above upper lip (Kottelat and Freyhof 2007) (Fig. 2). Maximal length and weight are 125 cm and 16 kg, respectively (Berg 1962; Birstein 1993; Freidrich et al. 2018). Maximum age is over 25 years (in aquaculture is even 33 years; Shljahtin 2006). Maturation is between 3–5 and 4–8 years for males and females, respectively (Reinartz 2002; Freidrich et al. 2018). Potamodromous (anadromous populations extirpated), occupying large rivers, usually in deep waters and with the fast current (Birstein 1993; Kottelat and Freyhof 2007). Spawns in April–June, on gravel and with strong current, where males dominate with 60–70% in number (Sokolov and Berdicheskii 1989). In the Danube River fecundity of the specimen (with body weight of 1 kg and age of 6+) is about 35,000 eggs (Ristić 1963c). Incubation lasts 4–5 days, after which larva drift in area with slow current and sand bottom (Sokolov and Berdicheskii 1989; Birstein

Fig. 2 Sterlets (*Acipenser ruthenus*), Danube, Serbia (Photo by M. Smederevac-Lalić)

1993; Reinartz 2002). Females are the first to leave spawning site, with males that follow, and swim downstream to sandbars and channels with the mud where they feed intensively (Sokolov and Berdicheskii 1989). During the winter, sterlets generally tend to stay in large shoals within deep sections of the river with good oxygen supply (Friedrich 2012). Natural hybrids with Russian sturgeon, beluga, ship sturgeon, and stellate sturgeon can occur (Tsekov et al. 2008; Dudu et al. 2011), with their increasing presence in the Danube River and Black Sea indicating decreasing trend in sturgeon stocks.

2.1.3 Conservation Status (IUCN Red List)

Endangered (EN), A2cde

Although local populations in the Danube River are still surviving, it is estimated that the native populations have declined by 60–70% over the last three generations (Gessner et al. 2022a).

2.2 *Acipenser Gueldenstaedtii Brandt & Ratzeburg, 1833 (Eng. Russian Sturgeon, Rus. русский осётр, Srp. руска јесетра, Hrv. Dunavska Jesetra, Slv. kašikar/Ruski Jester)*

2.2.1 Distribution (Past and Present) in Europe and Western Balkans

Used to occur in the Black Sea and its tributaries: the Danube (and its tributaries Olt, Sava, Tisza, Drava, Mura, Morava), Dnjester, Dnjeper, Don, and Kuban rivers (Freidrich et al. 2018). Prior to construction of Iron Gate dams on the Danube River, migrated upstream as far as Bratislava, sometimes Vienna and Regensburg (Birstein et al. 1997). In Western Balkans (Fig. 3), used to occur in the Croatian section of Drava and Sava rivers, as well as the Slovenian section of the Drava, Mura, and Sava rivers (Govedič and Friedrich 2018; Ćaleta et al. 2019). Ristić

Fig. 3 Past distribution of *Acipenser gueldenstaedtii* in Western Balkans

(1967a, b) reported Russian sturgeon spawning grounds in the Serbian section of the Danube River at 892, 903, 912, 929, and 944 rkm.

Although catch statistic of Russian sturgeon from Serbia section of Danube River suggested extinction risk by mid-twenty-first century (Lenhardt et al. 2006a), sporadic findings in this section, as well as trace element assessment of juveniles' pectoral fin rays, suggest existence of special resident (potamodromous) form (Hensel and Holčik 1997; Jarić et al. 2011b). However, sporadic findings of Russian sturgeon could also be attributed to escape or released specimens from aquaculture, so the only section of the Danube River drainage in Western Balkans to have wild specimens is downstream form Iron Gate 2 Dam.

2.2.2 Species Description, Biology, and Habitat

Number of dorsal scutes is 8–19, while number of lateral and ventral scutes is 24–50 and 6–13, respectively (Kottelat and Freyhof 2007). Lower lip interrupted in middle, with the base of not fimbriate barbels closer to tip of snout than the mouth. Maximal length and weight are 236 cm and 115 kg, respectively (Birstein 1993; Kottelat and Freyhof 2007) (Figs. 4 and 5) Average body length and weight of males are 129.5 cm and 12.7 kg (respectively), while average body length and weight of females are 145.8 cm and 22.12 kg (Alavi-Yaganeh and Falahatkar 2013; Freidrich et al. 2018). Maximum age for males is 52 years, while females max age is 62 years (Shljahtin 2006). Maturation for males is 8–13 years, while females maturation is 10–16 years (Shljahtin 2006; Kottelat and Freyhof 2007; Freidrich et al. 2018). Until maturation, they spend time in sea, on mud and sand bottom of estuary and near shore zones, where they feed molluscs, crustaceans, and small fishes (Sokolov and

Fig. 4 Russian sturgeon (*Acipenser gueldenstaedtii*), Danube, Serbia (Photo by Đ. Petrović)

Fig. 5 YOY Russian sturgeon (*Acipenser gueldenstaedtii*), Czech Republic (Photo M. Smederevac-Lalić)

Berdicheskii 1989). Depth range in sea is from 2 up to 100 m (Vescei 2001). In the big rivers they occupy deep waters (2–30 m) with moderate current (Vescei 2001; Birstein et al. 1997), where they spawn on rocky and gravel substrate (Vescei 2001; Bloesch et al. 2006). Spawning is in July, with temperature 17–23 °C (Kottelat and Freyhof 2007). During upstream migrations individuals swim near bottom, while on downstream swim near surface in the fast current (Ristić 1963a).

2.2.3 Conservation Status (IUCN Red List)

Critically endangered (CR), A2bcde

Rare in the Black Sea basin, with estimation of decline by 90% of natural populations over the last three generations, and with the Danube River migrants becoming extirpated within the next 10 years (Gessner et al. 2022b).

2.3 Acipenser Naccarii Bonaparte, 1836 (Eng. Adriatic Sturgeon, Rus. адриатический осётр, Alb. Blini I Adriatikut, Cnr. Jesetra Tuponoska, Hrv. Jadranska Jesetra, Slv. Jadranski Jester, Srp. јадранска јесетра)

2.3.1 Distribution (Past and Present) in Europe and Western Balkans

Was endemic in the Northern part of the Adriatic Sea, the Po River (and its tributaries), as well as Adige, Brenta, Bacchiglione, Piave, Livenza, Tagliamento, Sile, Soča, Cetina, Mirna, Raša, Zrmanja, Krka, Neretva, Bojana/Buna, Drin and

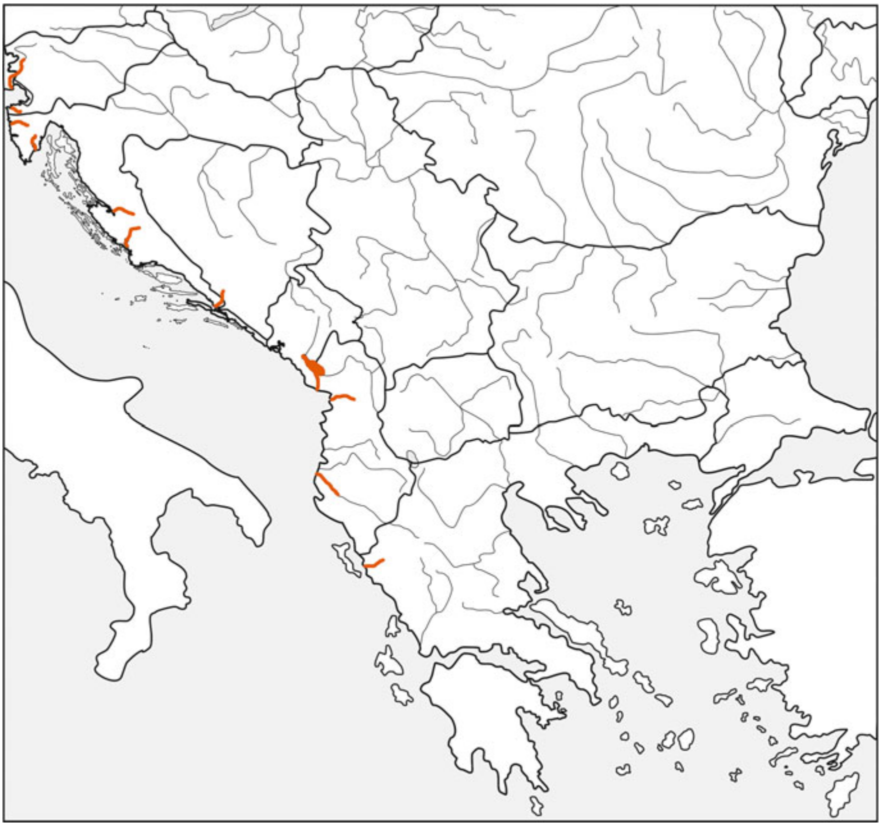

Fig. 6 Past distribution of *Acipenser naccarii* in Western Balkans

Vjosa rivers, as well as Skadar/Skodra Lake on the Montenegro-Albania border (Knežević 1985; Mrakovčić et al. 2006; Marić and Milošević 2011; Noakes and Bouvier 2013; Shumka et al. 2018; Freidrich et al. 2018; Ćaleta et al. 2019). Western Balkans (past) distribution in Fig. 6.

A small stock exists in the Po River, in a large part due to supportive stocking (Bronzi et al. 2022). In Western Balkans, statuses of species in Bojana/Buna and Drin rivers are unclear, although Ludwig and Kirschbaum (1998) reported presence of wild populations in Bojana/Buna basin.

2.3.2 Species Description, Biology, and Habitat

In dorsal row 10–14 scutes, while the number of scutes in lateral and ventral row are 32–42 and 8–11, respectively (Kottelat and Freyhof 2007) (Fig. 7). Barbels are not fimbriate, and their base is closer to tip of snout than to mouth. Snout is short and blunt, while lower lip is interrupted in middle (Kottelat and Freyhof 2007). Between

Fig. 7 Adriatic sturgeon (*Acipenser naccarii*) (Photo by T. Friedrich)

dorsal and lateral scutes, there are many small granuliform/star-shaped bony denticles (Kottelat and Freyhof 2007). Maximal body length and maximal body weight are 200 cm and 90 kg, respectively, while the average length is 100–180 cm (Hernando et al. 2009; Freidrich et al. 2018). Maximal age is over 50 years, while the age of first reproduction of males and females is 6–8 years and 8–13 years, respectively (Kottelat and Freyhof 2007; Freidrich et al. 2018). Anadromous species, but in sea remain in costal/estuarian waters (with depts at 10–40 m), while in freshwaters occupy large deep rivers (Bronzi et al. 2022). Hernando et al. (2009) reported presence of a landlocked population in the Ticino River. Reproduction occurs from May to July, on sandy and muddy substrate, with a rapid water flow (Bronzi et al. 2022). Benthic invertebrates and fish are main diet items (Kottelat and Freyhof 2007).

2.3.3 Conservation Status (IUCN Red List)

Critically Endangered (CR), A2bcde

Although restocking and possibly residual populations in Italy are thought to be slightly recovering, estimations are that natural populations decline by more than 99% over the last three generations, and it is now considered extinct from rivers in Croatia, Bosnia, and Herzegovina, Montenegro and Greece (Bronzi et al. 2022).

2.4 *Acipenser Nudiventris Lovetzky, 1828 (Eng. Ship Sturgeon, Rus. шип, Srp. сим, Hrv. Sim, Slv. Glatki Jeseter)*

2.4.1 Distribution (Past and Present) in Europe and Western Balkans

Common in the Danube River (Fig. 8) and its tributaries Sava, Tisza, Drava, Mura, Vah, Una, Kupa, Lonja, Maros, Morava, Prut, and Siret rivers (Hensel and Holčik 1997; Ćaleta et al. 2019). Historically, also present in Dnjester, Don, Kuban, Enguri, Rioni, and Sakarya rivers (Freidrich et al. 2018). Maximum body length and maximum body weight are 220 cm and 120 kg, respectively, while average length is 120,150 cm (Freidrich et al. 2018).

With only two specimens caught in 2003 and 2010 in the Danube River (Smonović et al. 2005; Guti 2011), and one in the Mura River in 2005 (Guti 2006), ship sturgeon is considered as possibly extinct in the Danube River Basin

Fig. 8 Past distribution of *Acipenser nudiventris* in Western Balkans

(Jarić et al. 2016; Freidrich et al. 2018). This is in concordance with a recent eDNA study, which didn't provide evidence for this species existence in the Danube River (Freyhof et al. 2022).

2.4.2 Species Description, Biology, and Habitat

Most distinguished characteristic from other sturgeons species in Europe is continuous lower lip, with no interruption in middle. Numbers of dorsal and lateral scutes are 11–17 and 49–74, respectively (Fig. 9). First dorsal scute is larger than the following ones, fused with the head (Kottelat and Freyhof 2007). Maximum body length is 220 cm, while maximal body weight is 120 kg (Freidrich et al. 2018). Average body length is between 120 and 150 cm. Life expectancy is over 30 years, with maximal recorded age of 36 years (Sokolov and Vasilev 1989; Freidrich et al. 2018). Forms both anadromous and resident populations, with only resident strain occupying the Danube River Basin (Hensel and Holčik 1997). Males spawn first time at 6–12 years, while females spawn at 12–18 years (Kottelat and Freyhof 2007; Freidrich et al. 2018). Spawning is from March to May in rivers main flow (fast current and water temperature 10–15 °C), with rocky and gravel bottom (Sokolov and Vasilev 1989; Reinartz 2002; Kottelat and Freyhof 2007). Males and females spawn every 1–2 and 2–3 years, respectively. Ship sturgeon spends the winter in deep areas with clay bottom, without feeding (Friedrich 2012). Feeds on a wide variety of molluscs, crustaceans, and benthic fishes (Kottelat and Freyhof 2007).

Fig. 9 Ship sturgeon (*Acipenser nudiventris*), Danube, Serbia (Photo by P. Simonović)

2.4.3 Conservation Status (IUCN Red List)

Critically Endangered (CR), A2cde

Although there are no recordings in the Danube River over the 10 years, it is suspected that this species has undergone a population decline of more than 99% in the past three generations (Freyhof et al. 2022).

2.5 *Acipenser stellatus Pallas, 1771 (Eng. Stellate/Starry Sturgeon, Rus. севрюга, Alb. Blini Turigjate, Cnr. Pastruga, Hrv. Pastruga, Slv. Pastruga, Srp. пасmрyгa)*

2.5.1 Distribution (Past and Present) in Europe and Western Balkans

In the Black Sea and its drainage, with the Danube River (and its tributaries Sava, Tisza, Drava, Mura, Jiu, Olt, Siret, and Prut rivers), Dnjeper, Dniester, Don, Kuban, Enguri, Rioni, Tskhenistskali, Coruh, Yesilirmak, Kizilirmak rivers, as well as in the Aegean Sea and its tributaries Struma/Strymonas and Evros rivers (Paschos et al. 2008; Freidrich et al. 2018). Western Balkans (past) distribution is in Fig. 10.

It is considered extinct in the Aegan Sea and upstream from Iron Gate dams in the Danube River (Paschos et al. 2008; Freidrich et al. 2018; Ćaleta et al. 2019). Small wild stock is restricted to the coastal waters of Romanian Black Sea section, with some indication of successful spawning in the Danube River (Holostenco et al. 2013).

2.5.2 Species Description, Biology, and Habitat

In dorsal row, there is between 9 and 16 scutes, while lateral and ventral row have 26–43 and 9–14, respectively (Kottelat and Freyhof 2007) (Figs. 11 and 12). Base of barbels closer to mouth than to tip of snout, with lower lip interrupted in the middle (Kottelat and Freyhof 2007). Maximal body length and weight are 290 cm and 80 kg, respectively (Freidrich et al. 2018). Average body length is between 120 and 180 cm, and maximal age is 35 years (Freidrich et al. 2018). Anadromous species, with spawning migration occurring from April to September. Some studies show that stellate sturgeon specimens feed at the river mouth until they reach 3–4 years old (Holostenco et al. 2013). Males reproduce for the first time at 6–12 years, while females reproduce at 8–14 years, with males and females reproducing every 2–3 and 3–4 years, respectively (Kottelat and Freyhof 2007; Freidrich et al. 2018). Females remain at spawning sites for 10–12 days, while males remain around six weeks (Kottelat and Freyhof 2007). Larvae lift in the water column and drift with current (Holostenco et al. 2013). Stomach content of juveniles, feeding in the river mouth

Fig. 10 Past distribution of Acipenser stellatus in Western Balkans

Fig. 11 Stellate sturgeon (*Acipenser stellatus*), Danube, Romania (Photo by S. Hont)

area of the Black Sea, contains little crustaceans and worms (polychaetes), while at sea it feeds on crustaceans, molluscs, and benthic and pelagic fishes (Kottelat and Freyhof 2007; Holostenco et al. 2013).

Fig. 12 YOY stellate sturgeon (*Acipenser stellatus*), Danube, Romania (Photo by S. Hont)

2.5.3 Conservation Status (IUCN Red List)

Critically Endangered (CR), A2bcde

After the construction of dam on the Volga River, *A. stellatus* had reduction by 40% of available spawning grounds in the upper reaches (Secor et al. 2000; Maltsev 2009). This species has undergone a population decline of more than 95%, in the past three generations (Mugue et al. 2022).

2.6 Acipenser Sturio Linnaeus, 1758 (Eng. European Atlantic Sturgeon, Rus. Атлантический осётр, Alb. Blini, Cnr. Jesetra, Hrv. Atlanska Jesetra, Slv. Atlanrski Jeseter, Srp. атланска јесетра)

2.6.1 Distribution (Past and Present) in Europe and Western Balkans

In the North Sea, with tributaries Eider, Elbe, Weser, Ems, Rhine, Maas, Scheldt, Thames, Trent, Severn, Seine; in the Atlantic Coast, with tributaries Loire, Gironde-Garonne-Dordogne, Adour, Douro, Guadiana, Guadalquivir; in the Mediterranean Sea, with its tributaries Ebro, Rhone, Saone, Tiber; in the Adriatic Sea, with tributaries Po, Adige, Isonzo, Soča, Mirna, Raša, Zrmanja, Krka, Cetina,Nereteva, Drin, Buna, Pinio, as well as Skadar/Skodra Lake; the Aegan Sea with tributaries Struma, Meric, Evros, Nestos, Pinos; in the Black Sea with tributaries Danube, Rioni, Ingouri, Kizilirmak, Sakarya (Knežević 1985; Sokolov and Berdicheskii 1989; Mrakovčić et al. 2006; Paschos et al. 2008; Marić and Milošević 2011; Freidrich et al. 2018; Ćaleta et al. 2019). Western Balkans (past) distribution in Fig. 13.

Present in the Gironde-Dordogne-Garonne Basin, with its marine distribution area extending from the Bay of Biscay to the North Sea (Freidrich et al. 2018). Talevski et al. (2009) suggest that *A. sturio* shouldn't be considered as the inhabitants of the Skadar/Shkodra Lake. Reports for the Ombla River near Dubrovnik (Croatia) are not confirmed (Ćaleta et al. 2019). Its presence in the Iron Gate area on the Danube River is highly unlikely, since last few specimens were caught during 1948–1954 period (Lenhardt et al. 2006a).

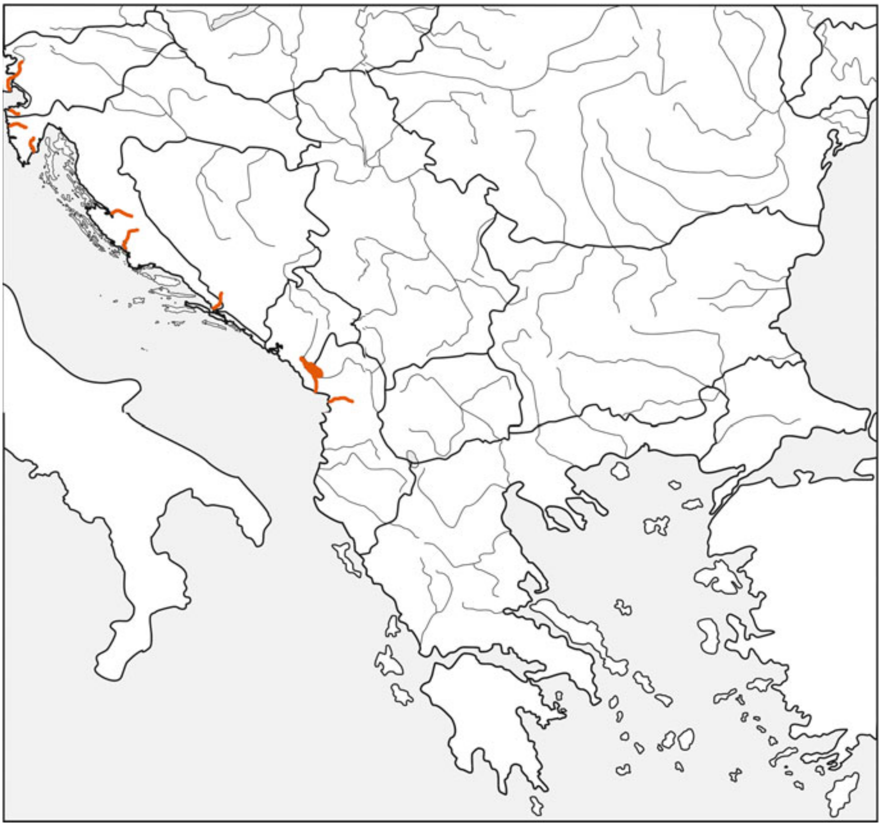

Fig. 13 Past distribution of Acipenser sturio in Western Balkans

2.6.2 Species Description, Biology, and Habitat

Number of dorsal scutes is 9–16, with first dorsal scute fused with head. Number of lateral and ventral scutes are 24–40 and 9–14, respectively (Kottelat and Freyhof 2007) (Fig. 14). There are many rhombic denticles between dorsal and lateral scutes (Sokolov and Berdicheskii 1989). Barbels are not fimbriate, and their base is midway between mouth and tip of snout (or closer to mouth). Lower lip interrupted in middle. Maximal length and weight are 600 cm and 1000 kg, respectively (Sokolov and Berdicheskii 1989; Kottelat and Freyhof 2007). Average body length is between 150 and 300 cm, and maximal age is over 60 years (Freidrich et al. 2018). Anadromous species, with spawning migration occurring from March to August. They migrate in the main river channel at depths of 2–8 m and temperature 12–17.5 °C (Sokolov and Berdicheskii 1989), with males entering rivers two three weeks sooner than females. Males reproduce for the first time at 10–12 years, while females reproduce at 13–16 years, with males and females reproducing every year and every second year, respectively (Kottelat and Freyhof 2007; Freidrich et al. 2018).

Fig. 14 European Atlantic sturgeon (*Acipenser sturio*) (Photo by I. R. Le Barh)

Their eggs are sticky and adhere to the bottom (Sokolov and Berdicheskii 1989), and incubation period varies from 3 to 14 days (depending on the water temperature). Juveniles spend their first years in the brackish waters (5‰ to 25‰) of the estuary zone before moving out to sea (Holostenco et al. 2013). In freshwater, juveniles feed on the larvae of aquatic insects, worms, and Mollusca (Sokolov and Berdicheskii 1989). Adults feed on benthic invertebrates (mollusca, polychaete, isopod, shrimps) and small fish (Sokolov and Berdicheskii 1989).

2.6.3 Conservation Status (IUCN Red List)

Critically endangered (CR), A2cde

This species has undergone a population decline of more than 99%, in the past three generations (Gessner et al., 2022c).

2.7 *Huso Huso Linnaeus, 1758 (Eng. Beluga, Rus. белуга, Alb. Blini Turishkurte, Cnr. Moruna, Hrv. Moruna, Slv. Beluga, Srp. моруна)*

2.7.1 Distribution (Past and Present) in Europe and Western Balkans

The Black Sea, with the Danube River and its tributaries (Sava, Tisza, Drava, Mura, Jui, Morava, Olt), Dnjepr, Dniester, Don, Kuban, Enguri, Rioni, Coruh, Yesilirmak, Kizilirmak and Sakarya rivers, and the Adriatic Sea and the Po River (Freidrich et al. 2018). Western Balkans (past) distribution in Fig. 15.

In the 1970s, species has been extirpated from the Adriatic Sea (Gessner et al. 2010).

Fig. 15 Past distribution of Huso huso in Western Balkans

2.7.2 Species Description, Biology, and Habitat

Number of scutes in dorsal, lateral, and ventral rows are 9–17, 37–53 and 7–14, respectively (Kottelat and Freyhof 2007) (Figs. 16 and 17). In mature specimen scutes are covered with a soft skin (Sokolov and Berdicheskii 1989). Crescent-shaped large mouth, with lower lip interrupted in middle. Maximal length and weight are 800 cm and 2000 kg, respectively, while maximum age is over 100 years (Freidrich et al. 2018). Anadromous species, and during its stay in marine environment it occupies pelagic zone, while descending as deep as 160 m, or even 180 m (in the Black Sea; Sokolov and Berdicheskii 1989). Its vertical distribution is varying due to availability of its food organisms. The Danube River migration starts in January (with early spring), or in the second half of March (late spring) at water temperature of 4–5 °C (Maximov et al. 2014). Maturation of males and females is 10–16 years and 14–20 years, respectively (Freidrich et al. 2018). During the mid-twentieth century, 24 years female had body length, weight and fecundity of 264 cm, 148 kg, and 594,000 eggs, respectively (Ristić 1963a). Danube specimens

Fig. 16 Beluga (*Huso huso*), Danube, Serbia. (Photo by G. Žikić)

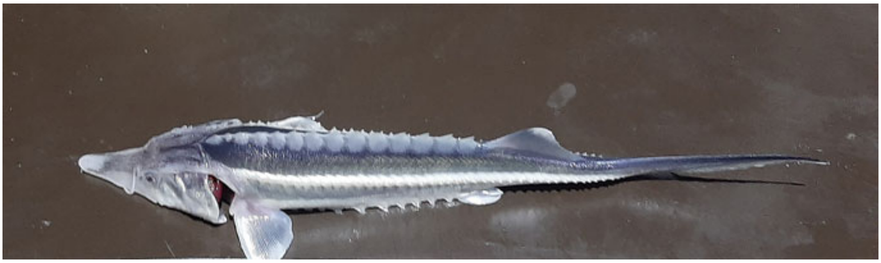

Fig. 17 YOY beluga (*Huso huso*), Danube, Romania. (Photo by S. Hont)

with Spawns every 3–4 years, during April–June, in strong-current habitats of large and deep rivers, with stone or gravel bottom (Kottelat and Freyhof 2007). They share the same spawning ground, in the same period of time, with sterlet (Holostenco et al. 2013). Larvae are pelagic for 7–8 days, and drift with current, while YOY migrates downstream in crowds during their first summer (Kottelat and Freyhof 2007). It is solitary species, but it agglomerates in larger groups during the winter (Maximov et al. 2014). Start feeding on vertebrates at a very early age, consuming shad (*Alosa* spp.), roach (*Rutilus rutilus*) and other fishes, with larger individuals consume aquatic birds and even baby seals (Sokolov and Berdicheskii 1989).

2.7.3 Conservation Status (IUCN Red List)

Critically Endangered (CR), A2bcd

This species has undergone a population decline of more than 90%, in the past three generations (Gessner et al. 2010).

3 Sturgeons Research (and Conservation Assessment) in Western Balkans

Sturgeons in Western Balkans region were group of interest for scientists over the 100 years, with most authors reporting them as part of fish communities in Albania (Poljakov et al. 1958), Bosnia and Hercegovina (Ćurčić 1910), Croatia (Trojanović 1934; Vuković and Ivanović 1971), Montenegro (Knežević 1985), Slovenia (Munda 1926). However, more thorough research started in the second half of the twentieth century, with the work of Janković (1958) and Ristić (1959, 1963a, 1963b, 1963c, 1967a, 1967b, 1967c, 1967d, 1969a, 1969b, 1970, 1971).

Although Taler (1948, 51) did report catch of two beluga from 1948, from the Sava River (near Lonje) and the Danube River (near Kladovo), with body weight 70 kg and 187 kg, respectively, along with report that the sturgeon catch in 1938 was 44,940 kg, most of information were description of beluga, ship, sterlet, Russian, Atlantic, stellate, Adriatic sturgeon distribution.

Perhaps first significant and detailed study of sturgeons in Western Balkans was survey on sterlet biology and ecology (Janković 1958), between 1951 and 1957. On the Danube River section, between 1215 rkm and 991 rkm, sterlets were analyzed for length-weight relationship, morphology, fecundity, diet, and age structure. Some conclusions were that sterlet catch mostly comprised of 3+ age specimens, with significant portion of 1+ and 2+ specimens, which suggests unsustainable spawning. Additionally, diet composition revealed that Trichoptera, Chironomidae, and Amphipoda were present through the year. Ristić (1959) was monitoring sterlet migrations (along with carp, catfish pikeperch, and bream) in the Danube, Sava, and Tisa Rivers, during 1952–1955, and reported both upstream and downstream migrations, with specimens almost reaching the Danube River Delta (in winter of 1955). Significant research was from 1951 to 1957 (Ristić, 1963a,b,c) when 6597 specimens of Russian sturgeon, beluga, stellate sturgeon, and sterlet were analyzed in the Danube River section from Sip (944 rkm) to Grabovica (886 rkm). List of islands and sand surges, along with table with fishermen data (number of fishermen on each sector, nets, hooks, type of gear), was provided. Some of the findings included males to female ratio for beluga (17.6:1), stellate (1.1:1), Russian sturgeon (2.6:1), based on which author concluded that spawning success would have negative trend. Provides description of beluga and Russian sturgeon, with the biggest specimens being 264 cm/148 kg (April 1955, near Sip) and 215 cm/47 kg (1951, near Sip), respectively. Data about spring and winter forms were provided, as well as average Russian sturgeon in Iron Gate section of the Danube River (20 kg, 17–18+, 125–135,000 eggs). Decline of catch was supported with data from the 1900s; Romania 350–400,000 kg, Bulgaria 12–150,000 kg, Serbia 120,000 kg annually, while in the 1960s all three countries had 120,000 kg annually. Ristić (1963b) also provided assessment of Atlantic sturgeon and ship sturgeon decline and gave insight about ship sturgeon protection (law in 1937), which was not successful. Data about stellate sturgeon and its catch in this section of the Danube River, from the 1890s and 1900s (average specimens of 180–200 cm, 80 kg, and fecundity for 15+, 13 kg, 145–160,000 eggs) was reported. Ristić (1963c) also provided description of sterlet and its two forms (long and short snout), biggest caught specimen (body length and weight 100 cm and 9 kg, respectively). It also provided data on correlation between water level fluctuation and catch of beluga, overview of age classes and spawning grounds (near Sip, Mala and Velika Vrbica, Milutinovac, Ljubičevac) in this section of the Danube River. Another detail and comprehensive survey was from 1948 to 1954 (Ristić 1967a, b, c, d) when 3151 specimen of Russian sturgeon (2269 males, 882 females) were assessed on the Danube River section between Sip (rkm 944) and Grabovica (rkm 886). Hydrological data (annual water flow of 5600 m^3/s) was available, with data of bottom substrate shift from rock/gravel (Sip), gravel/send (Davidovac-Kostel section) to gravel/sand/mud (Grabar), also available. Data of males to female ratio for spring and winter forms showed 4:1 and 1.9:1, respectively. Reports of Russian sturgeon catch were available, with highest being in Korbovo (rkm 912), then Sip, Ljubičevac, Davidovac-Kladušnica-Kladovo section, then Vajuga, and Kostel. Observation was that increase of velocity (m/s) and water level was good for spawning. Reports of spawning places for winter forms were at Sip, Ljubičevac, and Vajuga (with water temperature 6–11 °C), while spawning places for spring forms were Korbovo, Kostel, Davidovac, Kladušnica, and Kladovo (12–14 °C). Additionally, wintering places were reported at Sip, Vajuga, Ljubičevac, with possibly at Veliki and Mali Kazan, Golubinje, Gospojin Vir, Brnjica. Data was provided for age structure of winter forms (8–14+ in males and 10–23+ in females) and spring forms (7+ in males and 10–12+ in females). Conclusion was that the populations are decreasing. Following years, Ristić (1969a, b, 1970, 1971) provided comprehensive data for sterlet. From 1949 to 1967 (Ristić 1969a), 5137 sterlets were analyzed in the Danube, Sava, and Tisza Rivers. Ratio of specimens younger than 4+ in total catch was 94–99% in upper section, 50–53% in mid-section, with 79% in lower section of the Danube River, while in the Sava River it was 92% and in the Tisza River 93%. This survey provided basis for protection by defining protective measures (47 cm for sterlet total length, age of 4+, mash size for nets >45 mm). In a survey (Ristić 1969b) at the Danube River between 1142 and 1144 rkm, 1975 specimens were collected, along with geological and hydrological data. Age structure of population was assessed, with 0+/1+ (41%), 2+/3+ (42%) and 3+/and older (17%). Recaptured specimens (1.8% of all marked specimens) couldn't provide some reliable conclusions. Some conservation measures were recommended, such as ban on sterlet rings and nets with mesh size smaller than 50 mm, with also suggestion to put the fishing ban for 60 days (between April–May). Also, Ristić

(1969b) reported spawning places in the Danube River, at 1312 rkm, 956 rkm, 944 rkm, in the Sava at 149 rkm, and in the Tisza at 134 rkm. In 1952–1962 survey (Ristić 1970) on the Danube River, marked and recaptured sterlet showed that they migrated mainly downstream, with distances from 210 km to 322 km, and even 524 km. Analysis of 7313 sterlets in the Danube, Sava, and Tisza Rivers (Ristić 1971), during 1948–1969, provided data on two morphs, short and long snout. With the age of specimens between 0+ and 19+, of total number of samples, specimens with long snout were prevailing (67%), with 33% of short snout. Observation of spawning dynamic shows that short snout specimens and long snout are successive (long snout starlet arrives after short snout).

During the 1980s and 1990s, sporadic reports of sturgeons were part of fish community surveys in Albania (Rakaj 1995) and Montenegro (Knežević 1985; Marić, 1995), while reports in Slovenia focused on sterlet (Pintarič 1982; Gregori 1988; Jeremko 1998). Despite construction of Iron Gate dams, research in Serbia (Stamenković 1991; Janković 1993) was still focusing on that section of the Danube River, with reports of decrease in numbers of localities for fishing sturgeons and mass upstream migrations of sterlets after construction of the dams.

At the beginning of the twenty-first century, number of publications concerning sturgeons and their protection in Western Balkans rapidly increased (Lenhardt et al. 2004, 2005a, 2006a, 2009, 2012, 2014; Jarić et al. 2009a, b, 2010, 2011a, b, c, 2014, 2015; Smederevac-Lalić et al. 2011; Cvijanović et al. 2015, 2017). Although beluga, Russian sturgeon, Atlantic sturgeon, and ship sturgeon are investigated (Lenhardt et al. 2005a, 2006a; Jarić et al. 2009b, 2011a), main focus was on sterlet (Lenhardt et al. 2004, 2009, 2012; Ognjanović et al. 2008, Jarić et al. 2011c; Cvijanović et al. 2015, 2017), with nonindigenous paddlefish (*Polyodon spathula*) and Siberian sturgeon (*Acipenser baerii*) also subject of interest (Lenhardt et al. 2006b; Jarić et al. 2019; Govedič and Friedrich 2018). Sterlet survey in the Danube River, between 2002–2003 (Lenhardt et al. 2004) showed shift of length-frequency distribution toward lower length classes, as well as decrease in sterlet catch. In spring and fall of 2001, at the Danube River downstream from Iron Gate 2 dam, females of beluga, Russian sturgeon, and sterlet were used for comparative study (Lenhardt et al. 2005a) of the biometry, gravimetry, and protein contents of the oocytes. It showed that beluga oocyte diameter, volume, wet and dry mass were the largest followed by Russian sturgeon, then starlet. Oocyte water and relative protein content of all three sturgeons were very similar, with the water content results at the lower range. Based on the beluga and Russian sturgeon catch data (period 1960–1997) time-dependent model was deployed (Lenhardt et al. 2006a), and it predicts extinction of Russian sturgeon around the middle of century, with beluga being extinct at the middle of the millennium. Existence of two morphs in sterlet, short and long snout, was discussed in Ognjanović et al. (2008). Lenhardt et al. (2008) provide data on sturgeon catch decline in the Danube River, as well as review of scientific research and activities related to their protection. Change in Fulton's condition factor in juvenile sterlets during the year was reported by Lenhardt et al. (2009). Additionally, difference in hepatosomatic index, which is due to difference in sterlet diet in nature through the year, was also reported, as well as prevalence and intensity of parasite *Skrjabinopsolus semiarmatus*. Jarić et al. (2009a) assessed different population viability analysis (PVA) methods and models developed for sturgeon species and suggested that all sturgeon PVAs generally produced the conclusion that slow physical growth and discontinuous spawning of sturgeons result in low intrinsic population growth rates, slow recovery from exploitation, and high sensitivity to harvest. Additionally, they suggested that the minimum length limit should be at least several cm longer than the length at which individuals reach maturity in order to enable at least one or two spawning events to occur prior to harvest. Also, authors concluded that stocking can represent only a temporary measure, and restoring the spawning habitat remains the only long-term solution for maintaining viable populations. Another analysis (Jarić et al. 2009b) deployed five different statistical methods, based on sighting data, for assessment of sturgeons extinction probability. All methods provide significant probability that the Atlantic sturgeon is extinct (from '66 and '70), while it suggests that ship sturgeon is still present, but it will be extinct in the next couple of decades. Another PVA analysis (Jarić et al. 2010) revealed a large sensitivity of the Danube sturgeon populations to changes in the natural mortality, fecundity, age at maturity, and spawning frequency. It showed that species with the lowest proportion of the adults in a population, such as the ship sturgeon and the Atlantic sturgeon, were also much more vulnerable than the other species at the same population size. Sterlet has higher adult mortality than the other sturgeon species, which probably reduces the positive effects of the stocking with adults. Analysis (Jarić et al. 2011b) of Sr:Ca ratio in the fin ray of the juvenile Russian sturgeon caught below the Djerdap II dam indicates that this individual has never left the freshwater. This finding could be explained either by the theory of existence of a special resident, potamodromous form of the Russian sturgeon in the Danube or as a specimen escaped or released from some aquaculture facility. Accumulation of heavy metals in muscle, liver, and gills of sterlet was assessed in Jarić et al. (2011c), and liver appeared to be the main heavy metal storage tissue, while the lowest levels of analyzed metals were in muscle. Status and trends in management of sturgeon species and the development of its aquaculture (in Romania, Bulgaria, Serbia, Ukraine, and Moldova) was assessed in Smederevac-Lalić et al. (2011). Statistical analysis (Lenhardt et al. 2012) of 15 morphological traits of wild and reared sterlets showed significant differentiation in 11 traits, with reared specimens having significantly shorter pectoral fins and stockier body. Lenhardt et al. (2014) gave insight to impact of pollution on sterlet, genetic analysis of the Danube sturgeons, sturgeon catch and protection in Serbia. Jarić et al. (2014) assessed trends in modeling over time within sturgeon research and show that population models mainly focused upon the impact of fisheries, dams, stocking, genetics, and sensitivity analysis, while habitat suitability models, hydrodynamic models, bioenergetic models, and general statistical models focus on species distribution, survival, growth, and spawning migrations. A simple life-table metamodel was introduced by Jarić et al. (2015), which facilitates population and fishery assessments across entire groups of fish. The method also allows utilizing life history data from well-studied species to infer fishing mortality thresholds for other, poorly studied species within the same group. Input parameters required to apply the presented approach include female fecundity, age at maturity, longevity, adult, subadult and YOY survival, and spawning frequency. During 2007–2009, wild starlet populations, from Middle and Lower Danube and Lower Tisza rivers, were investigated (Cvijanović et al. 2015; Cvijanović et al. 2017) for genetic diversity with the use of mtDNA and microsatellite loci. These analyses showed variation in the detection of a genetic bottleneck, as well as revealing different effective population size.

Recently, new data on distribution and assessment of sturgeons in Western Balkans were available in Albania (Shumka et al. 2018), Croatia (Ćaleta et al. 2019), and Slovenia (Govedič and Friedrich, 2018). Also, ongoing research of sterlet in the Danube River (project WePass 2), provides some insight into migration patterns. Sterlet specimen caught and tagged in October 2021, near Ljubičevac (890 rkm), was detected some 14 days later downstream, at the 600 rkm (Cvijanović et al. unpublished data). Data suggest that tagged sterlet migrated downstream through turbines, which is in concordance with conclusion of Honsig-Erlenburg and Friedl (1999). However, sterlet specimens caught near Ljubičevac (890 rkm) in Jun 2022, tagged and released downstream at Prahovo (860 rkm), were migrating upstream and reached Iron Gate 2 Dam (Cvijanović et al. unpublished data).

4 Parasites and Food Composition

Sturgeons are unique among fish, in possessing a remarkably diverse assemblage of host-specific parasites (Skryabina 1974; Choudhury and Dick 2001). Information on the sturgeon parasites composition and distribution are summarized (see Table 1 from Choudhury and Dick 2001). The parasites of acipenserids (sturgeons) exhibit no apparent specificity for either of the two major lineages of sturgeons, Huso or Acipenser L., where their species coexist (Ponto-Caspian region and Amur River drainage). Only two parasites, *P. hydriforme*, considered by Raikova (1994) to be an "ancient parasite," and the intestinal fluke, *Crepidostomum auriculatum* Wedl, occur in every major drainage basin where sturgeons occur (Choudhury and Dick 2001). The absence, in Europe, of *C. auriculatum* in acipenserids other than the sterlet (*A. ruthenus* L.) is noteworthy and, lacking satisfactory contemporary ecological reasons, requires a historical explanation. Its presence in sterlet in the Ponto-Caspian drainage (Skryabina 1974; also lists a historical record in the Rhine) may be the result of a single dispersal event as recent as the Pleistocene. The highest number of endemic parasites is found in sturgeons of the Ponto-Caspian basins (seven parasite species).

The parasite fauna supports the hypothesis of a former continuous distribution of Nearctic and eastern Palaearctic (Siberian) sturgeons that was subsequently fragmented by geological and climatic events, resulting in major displacement of ancestral sturgeon populations in North America. The parasites also reflect a historical connection with marine and brackish water environments that pre-dates the diversification of sturgeons, indicating that ancestral acipenserids were diadromous (Choudhury and Dick 2001). The parasites of sturgeons have been studied by several authors (Dubinin 1952; Dogiel and Bykhovskiy 1939; Shulman 1954; Nechaeva 1964; Skryabina 1974).

Sterlet presents the only sturgeon species which is a still numerous in the Serbian part of the River Danube. The sterlet collected along the Danube's course through the Belgrade Region were examined and 13 helminth species have been recorded: four species of Trematoda (*Skrjabinopsolus semiarmatus*-dominant species, *Sanguinicola inermis*, *Posthodiplostomum cuticola* and *Azygia lucii*), one species of Cestoda (*Amphilina foliacea*), four species of Nematoda (*Contracaecum bidentatum*, *Contracaecum sinipercae*, *Cystoopsis acipenseris,* and *Capillospiura ovotrichuria*) and four species of Acanthocephala (*Acanthocephalus anguillae*, *Acanthocephalus lucii*, *Pomphorhynchus laevis* and *Pomphorhynchus bosniacus*). Three of these mentioned species are specific for representatives of Acipenseridae—*Skrjabinopsolus semiarmatus*, *Contracaecum bidentatum,* and *Amphilina foliacea* after Moravec et al. (1989), also according to the opinion of Kakacheva-Avramova (1983), who listed the above-mentioned species and the species *Cystoopsis acipenseris*, while many other parasite species of fish host other types of parasites.

Relevant researches on the parasite fauna of sterlet in the Danube River are very rare (Moravec et al. 1989). In Serbia, only a few data are able to cited here: Jankovic (1957); Cakić (1986a, b). Janković (1957) reported the following endo-parasitic species—*Amphilina foliacea*, *Ascaris* sp., *Echinorhynchus gadi*, and undetermined representatives from Class Trematoda, Subclass Digenea. After almost 30 years, by examination of Danubian starlet helminths, the presence of three helminth parasitic species—*Skrjabinopsolus semiarmatus*, *Contracaecum bidentatum,* and *Acanthocephalus anguillae*—has been published (Cakić et al. 2008).

The main food of the sterlet is various benthic organisms, the most important of which are insect larvae, primarily Chironomidae, Trichoptera, Ephemeroptera, and Simuliidae. It also feeds on larvae of Plecoptera and Heleidae, small molluscs of the genera Sphaerium, Pisidium, and Viviparus, representatives of Oligochaeta, Polychaeta, Hirudinea, and other benthic invertebrates. During the spawning period of other fish species, a significant part of their diet is their eggs.

After study of Ristić (1970), there were only sporadic research activities, mostly focused on sterlet food composition, growth, and length-weight relationship (Janković et al. 1994). More detailed analyses were originated at the beginning of the twenty-first century. In 2002 and 2003, research conducted on specimens collected from the Danube near Belgrade involved analysis of morphological variability, sterlet growth, and its parasites (Kolarević 2004; Lenhardt et al. 2004, 2009).

The diet of sterlet mostly comprised bottom fauna taxa. Sterlet in the Danube feed mainly on larvae of Trichoptera, Chironomidae (Diptera), and Gammaridae (Amphipoda) throughout the year and represented the main part of its diet (Janković 1958). In a study conducted in 1986, Trichoptera and Chironomidae were again found to be the main source of its food in the Danube River, while its main food in the Danube section between the two dams in the Djerdap gorge were Hirudinea (91%), which is probably due to the shift in benthic fauna composition caused by the impoundment by the dam (Janković et al. 1994). The most recent studies of sterlet nutrition, conducted by Lapkina et al. (2005), have shown that Chironomidae were dominant sterlet food in July, while the leeches were dominant in August and September (representatives of six genera and three families). Leeches represented 100% of the sterlet diet during September, which has led to an increased sterlet growth (2.2 g/day), in comparison with its growth in July (1.8 g/day; Lapkina et al. 2005).

Analysis of data for sterlet's diet on nine locations along the Danube River in Serbia showed that a total of 12 groups of food of invertebrate fauna have been identified. Trichoptera (3.16–54.43%), Chironomidae (4.32–95.77%), and Gammaridae (0.51–98.61%) comprised the main part of sterlet diet, especially in sector 1189–1043 rkm, with a reduction in food composition variability close to the Djerdap I dam and in the reservoir between the two dams. The other components of the diet were Corophium sp., Asselus sp., Mollusca, Oligochaeta, Annelida, Insecta, Nematoda, and Hirudinea. The organisms typical of lithorheophilic and psammorheophilic biocoenoses play a considerable role in the diet of the sterlet. Composition of bottom fauna as food items varies due to changes in environmental conditions induced mainly by the construction of two dams: Djerdap I (943 river km, 1970) and Djerdap II (863 river km, 1984) (Djikanovic et al. 2015).

Comparing seasonal aspects of sterlet feeding in the River Danube shows that the same bottom fauna groups participate in its diet throughout the year with some differences in prey proportions according to season. Stomach contents depend on the bottom fauna composition of each river sector as well as of sampling season. In May, Trichoptera, Amphipoda, and Hirudinea were most abundant, whereas in September and October, representatives of Chironomidae, Oligochaeta, Gammaridae, and Corophium sp. were mainly present in the diet (Janković 1958; Janković et al. 1994; Strelnikova 2012). Upstream of the Belgrade section, Chironomidae and Trichoptera have great importance in the sterlet diet. In the Belgrade section Amphipoda and Hirudinea are also important, whereas Oligochaeta, Gammaridae, and Chironomidae are also important in the downstream sector (Janković 1958; Janković et al. 1994; Strelnikova 2012).

Analysis of data on the structure of the macrozoobenthos community before construction of the Iron Gate Dam on the River Danube and after its construction indicates that certain global changes have occurred in the structure of this community. Among these changes are decreases in the abundance of populations of amphipods, some species of gastropods and bivalves, and increases in the abundance of pelophilous and phytophilous forms of the group Oligochaeta and pulmonate gastropods (Simić and Simić 2004). The abundance of amphipod crustaceans, especially species of Ponto-Caspian origin, has declined in the Iron Gate region. Representatives of Gammaridae and Corophium sp. were encountered in later years (Simić and Simić 2004). It can be seen from the results that Ponto-Caspian species such as Corophium sp. is more sensitive than Gammaridae (Simić and Simić 2004). During research conducted under the international project "Joint Danube Survey 1 and 2," Mollusca dominated both in terms of the number of species and their relative abundance, followed by representatives of Chironomidae and Oligochaeta (Paunovic et al. 2010).

Future effects of climate change on benthic macroinvertebrates in the Danube River are expected. Pressures on the Danubian aquatic biodiversity, particularly on the aquatic macrozoobenthos community, as a food resources, come from the invasion of non-native species, as well as from land use change, water stress, pollution, habitat fragmentation, flow regulations (DRB climate change adaptation, ICPDR, 2017–2018). Impacts on macrozoobenthos are: (1) Changes in timing and magnitude of low flow and flood events; (2) Changes in the hydrological regime may create new conditions to which existing hydrobionts can be poorly adapted; (3) increase of water temperature during summer months can lead to reduced oxygen and CO2 solubility pressuring macrozoobenthos community structure and composition (taxa correlated to high temperature, including some dipterans and oligochaetes, might benefit from global warming and increase their abundance and range of distribution).

Differences in invertebrate community composition during JDS expedition are recorded. Compared to the results from JDS3 (2013), a similar diversity pattern occurred, however, the number of taxa of Gastropoda groups found during JDS4 (2019) has doubled. On the other hand, several Ponto-Caspian species native to the Lower Danube River stretch found during JDS3 were now seen to be missing. In addition, species from genus Pisidium sp. are completely missing in the taxa lists from the middle and lower reaches. Changes in the macrozoobenthos community can greatly affect the starlet population as well as their food source, and perhaps influence their feeding patterns. Also, changes in macrozoobenthos could effect on the presence of some helminths species in the starlet intestine, their prevalence, and intensity of infestation.

5 Review of Legislation Measures in Force

On the European continent the Danube and Rioni River remained refuges of critical importance for the last reproducing wild sturgeon populations. Recent assessments of the sturgeon stocks are based on a very scattered and patchy set of incoherent information. Danube Basin countries and the Black Sea range states of Turkey and Georgia adopted the Pan European Action Plan for Sturgeons and agreed to fully implement the comprehensive set of measures (Recommendation No. 199 (2018) of the Bern Convention).

The conservation of migratory fish species, particularly sturgeon species, protection of their habitats, and ecological corridors are covered in most of the countries in their conservation, biodiversity policy or river management, particularly with regard to the implementation of WFD requirements. But, plans on the national or regional level often do not explicitly target particularly sturgeon species. This reflects the often-general nature of national conservation and biodiversity policy plans rather than a certain measure for protection of species and habitats.

Sturgeons are in general covered by various national legal instruments, fishing regulations, bans and restrictions, but protection of these species needs a holistic approach connecting international waters, coastal areas and river systems, including a well-coordinated national and international legislation (Bern Convention, the Bonn Convention on Migratory Species, CITES, Habitats Directive, Water Framework Directive or the Marine Strategy Framework Directive). In 2019 representatives from the Danube Basin and the Black Sea issued the Galati Declaration on Sturgeon Conservation in the Danube Basin and Black Sea. That was the first ever joint discussion of 120 delegates of fisheries, water and environmental administration, scientific community and civil society from Danube and Black Sea states about necessary conservation measures, and urgent need for population monitoring as a prerequisite to conservation measures (DSTF). All of these policies are the first step in structuring and implementing successful conservation programs worldwide and providing the necessary tools for effective international control. Government decisions and policies should be based on the results of scientific investigations. A common proactive approach of monitoring and regulating of endangered sturgeon species will lead to the recovery of the populations (Bănăduc et al. 2016).

The Bern Convention is focused on European nature protection, for both members and some non-member countries of Europe. This agreement is relevant to the protection of listed species in the Balkans. It includes annexes of species, with varying levels of protection, listed under Appendix II (Strictly Protected Fauna) or Appendix III (Protected Fauna) of the Bern Convention. Citizens may issue complaints concerning the lack of implementation.

The European Habitats Directive (92/43/EEC) is the backbone of legally binding European species protection and conservation. The relevant appendices are Appendix II (species of community interest, for which protection areas must be assigned), Appendix IV (strictly protected species), and Appendix V (species whose exploitation is compatible with a favorable conservation status) (Weiss et al. 2018).

Action Plan for the conservation of Sturgeons in the Danube River Basin was submitted and approved in the Bern Convention and was adopted by all Danubian countries. Sturgeon Action Plan is an important document and it was expected to be legally binding instrument (Bănăduc et al. 2016). But was never truly implemented despite being supported by a wide range of protective international legislation. In 2012 the Danube Sturgeon Task Force (DSTF) was established as a network of dedicated volunteers from scientific, governmental, and nongovernmental organizations. The Sturgeon Action Plan was updated and streamlined into the program "Sturgeon 2020" (Freidrich 2018).

The list of the protecting international legislation that imply on the sturgeon fish species and that are adopted by the Western Balkan countries: CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), Bonn (Convention on the Conservation of Migratory Species of Wild Animals), Bern (Bern Convention on the Conservation of European Wildlife and Natural Habitats), CBD (Convention on Biological Diversity), Ramsar (Convention on Wetlands) (Freidrich 2018).

The CITES was probably the most significant international act protecting sturgeons. Listing of the sturgeon species on Annex I and II which defines whether or not there is a possibility of placing it on the market with special permits, system of export quotas, an universal labeling system for the identification of caviar, international cooperation and harmonization of management and conservation measures, joint stock assessment and enhancement, and an improved monitoring and reporting as well as sustainable management measures put in force such as moratorium indicated that only the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) had and real effects in the implementation process (Jarić et al. 2017).

The moratorium was introduced by national governments in 2006 (under the CITES guidelines) for a period of ten years, in response to the rapid decline of migratory sturgeon species in Europe. That was drastic policy intervention that affected local fisheries in the Danube River basin. The ban was extended 2016 for another at least five years. The ban covers five species of sturgeon from the Danube River basin—Russian sturgeon, sterlet, stellate sturgeon, beluga, and ship sturgeon. Although this fishing ban is considered an important step toward sturgeon conservation, it reduces the ability to estimate sturgeon stocks. However, recent findings confirm that the ban does not prevent poaching (Teodorescu and van den Kommer, 2020).

5.1 Serbia

The management of the sturgeon species in Serbia is addressed by the following national legislations: Law on Protection and sustainable use of the fish resources (Official Gazette of the RS, no. 128/2014 and 95/2018—other laws) and a set of by-laws: Order of measures for the preservation and protection of the fish stock (Official Gazette of the RS, no. 56/ 2015 and 94/2018), The Decree of fishing tools, fishing methodology and facilities for commercial fishing, as well as on the method, tools, equipment, and means used for recreational fishing (Official Gazette of the RS, no. 9/2017 and 34/2018). Law on Nature Protection (Official Gazette of RS, No. 36/2009, 88/2010, 91/2010–amended, 14/2016 and 95/2018–other laws), Rulebook on the proclamation and protection of strictly protected and protected wild species of plants, animals, and mushrooms (Official Gazette of RS, No. 5/2010, 47/2011, 32/2016 and 98/2016). For the strictly protected wild fish species (such as sturgeons), prohibition of their use, destruction and all actions that may threaten wild species and their habitats is defined. Also, measures and actions to manage their population is proscribed. In Serbia, all 5 sturgeon species are protected by the ban: Russian sturgeon, sterlet, stellate sturgeon, beluga, and ship sturgeon. Fishing on sturgeons is prohibited, except for scientific research purposes, and the most important measures are aimed at preserving their habitats in relation to the space they inhabit and the quality of the habitat itself.

5.2 Slovenia

Sterlet was one species of sturgeon included in the Slovenian freshwater fish species list because it was caught during the 80s and 90s of the last century. Since 1992, it has been listed on the Red List of freshwater fish of Slovenia, firstly assessed as "extinct" and fully protected (Ur. l. RS 1993). Then the status was changed to "rare" in 2003 (Ur. l. RS 2002) and remained protected (Ur. l. RS 2004). Other Danube sturgeons are not specially assessed by national legislation, except European sturgeon that is included in the list of marine fish as endangered (Ur. l. RS 2002) (Govedič and Friedrich 2018).

5.3 Croatia

The only sturgeon species listed in Croatian regulation regarding closed season and minimal catch size is sterlet. The moratorium on sturgeon fishing in Croatia was not established due to strong resistance from commercial fishermen, so the catch quota was reduced (Piria, personal communication). Catch quota according to new Freshwater Fisheries Act from 2019, for sterlet catch from the Sava is 100 kg and from the Danube fishing zone is 500 kg. Closed seasons last from 1 March–31 May and minimum catch size is 40 cm for the only sturgeon species listed in Regulation in force from 2005 on the protection of fish in freshwater fisheries. Fish species that are strictly protected by the Nature Protection Act under threatened category RE are Russian sturgeon, stellate sturgeon, Atlantic sturgeon, beluga, and ship sturgeon while Adriatic sturgeon is evaluated as CR (EN).

5.4 Bosnia and Herzegovina

Fishing in Bosnia and Herzegovina is regulated by the following laws and by-laws depending on the entities:

Laws regarding the protection and preservation of wildlife and fish fauna:

Law on Environmental Protection (Official Gazette of FBiH no. 33, 2003).

Order on new measures for research or conservation to prevent a significant negative impact on species by deliberate capture or killing of species (Official Gazette of FBiH no. 65, 2006).

Law on Environmental Protection (Official Gazette of RS no. 113, 2008).

Order on the establishment of a monitoring system for the deliberate keeping and killing of protected animals (Official Gazette of RS no. 113, 2008).

Law on Environmental Protection (Official Gazette BD no. 24, 2004).

Fisheries and Aquaculture Laws:

Law on Freshwater Fisheries (Official Gazette of FBiH no. 64, 2004).
Law on Freshwater Fisheries (Official Gazette BD no. 35, 2005).
Law on Fisheries (Official Gazette of RS no. 72, 2012).
Sturgeon species are protected by the closed season and minimal catch size. Sterlet is protected from 1 March to 31 May, minimal catch size 40 cm, while sturgeon closed season is in April and minimal catch size 50 cm.

5.5 Montenegro

Fishing in Montenegro is regulated, by several documents. In case of freshwater fishing, currently there are two basic documents: Freshwater Fishing and Aquaculture Act, from 2018 (Zakon o slatkovodnom ribarstvu i akvakulturi, broj: 01–290/2, od 16.03.2018. god.) and Order on Prohibitions and Restrictions on Fishing and Protective Measures of Fish Fund, dated May 27, 2016 (Naredba o ribolovnim zabranama, ograničenjima i mjerama za zaštitu ribljeg fonda," broj 33/2016, od 27.5.2016. god.). There are no explicit legislation measures regarding sturgeons species.

5.6 Macedonia

Fishing in Macedonia is regulated by the Fisheries Law, which deals with commercial fishing, sport fishing, and fish production. There are no explicit legislation measures regarding sturgeons species.

5.7 Albania

This Law on Fisheries (No. 80/2017, 64/2012) regulates all fishery activities and their management and aims at ensuring the protection of the marine life and internal waters. Article 37 prohibits the fishing of sturgeon—Atlantic sturgeon, in particular catching, keeping or transiting on board, intentional landing and marketing of the following marine organisms, including for human consumption, is prohibited at any time, in any area, and using any type of equipment or gear (https://www.faoadriamed.org/html/legislation/LegALBComp.html).

Major deficits in the management and policy relate to their implementation. Different legal, strategic, and management documents must be better harmonized. Data related to sturgeons monitoring are lacking in practice. This is the case even if such assessments are required by nature and biodiversity protection plans or river basin management. Example in Serbia: The call for sterlet monitoring was announced but never finished tender procedure and put in motion. Development of specific regional, national, and international Action Plans for the Danube sturgeons are efforts of the experts to help policy and management to respect minimum ecological requirements as well as to identify and promote compromise solutions for their protection (Measures project).

6 Aquaculture

Aquaculture plays a very important role in the reproduction of endangered fish species, as well as the breeding of their fry for stocking purposes, especially for endangered species such as sturgeons in the waters where their numbers have declined, their introduction into waters from which they have disappeared (reintroduction) or for further breeding in ex situ conditions (Marković et al. 2016). The basic idea of ex situ is to establish closed life cycle units, which should serve as living gene banks and at a later stage releasing them into the nature should stabilize and strengthen wild populations (Freidrich et al. 2018). Numerous attempts to stabilize populations by hatchery and release programs have been made in the Danube over the past few decades. Sterlet was example of such efforts (Lenhardt et al. 2020). In order to prevent the occurrence of inbreeding and outbreeding, genetic assessments of the suitability of specimens intended for stocking should be recognized as a priority, therefore ex situ measures cannot be sustained without in situ measures and must always be linked to the natural population in order to maintain the natural gene pool and it is still just solutions until in situ habitats and populations are re-established (Lenhardt et al. 2020; Freidrich et al. 2018). Hatchery should provide semi-natural conditions to allow the sturgeon to adapt in the wild and exhibit home behavior based on conditions such as water chemistry, diet, flow rates, temperatures, etc. (Freidrich et al. 2018).

6.1 Serbia

According to the Law on Protection and Sustainable Use of Fish Stocks (Official Gazette of RS, No. 128/2014), stocking of a fishing area may be conducted only with autochthonous specimens reared by the organization with special competences, as defined by special regulations, while the Public Procurement Law (Official Gazette of RS, No. 124/2012) established that all fishing area stakeholders are obliged to invite for public procurements. Complicated public procurement procedures make such companies discouraged to produce specific stocking material. In addition, there are also no governmental subventions for these purposes, and when faced with the limited and unreliable market, hatcheries become reluctant to invest in certain species. Additional problem is inadequate knowledge of broodstock origin and the absence of broodfish tagging. This can lead to outbreeding errors and consequently to serious negative effects in wild populations. Potential and planned stocking programs in Serbia are therefore postponed (Lenhardt et al. 2020).

There was one facility, located in Kusjak (Fenix) near the Iron Gate II dam, where beluga and Russian sturgeon were kept and attempted to hatch.

Aquaculture facilities for sturgeons in Serbia are situated in the Vojvodina autonomous province, near Bačko Petrovo Selo (PR STR TISA), Temerin (Mehanika Group), Plandište (Fish cooperative MALGURA), Vršac (two companies, Aquacultura and Fish Farm) and Ledinci (Ledico Food). All six facilities are raising sterlet, with five facilities also raising Siberian sturgeon, two are raising Russian sturgeon and one facility is raising hybrid (Acipenser baerii x Acipenser ruthenuss). All facilities are private property. Unfortunately, they were not established as an ex situ facility, but rather for commercial purposes. Also, these were not registered objects by the authorized Ministry for Environment.

6.2 Slovenia

Slovenian hatcheries breed at least three sturgeon species: indigenous sterlet, nonindigenous Siberian sturgeon, and paddlefish. According to a recent study (Govedič and Friedrich 2018) sterlets have been reared in Požeg water reservoir, also in Turn ponds (Turnovi ribniki) in the area of Rače. Paddlefish were cultivated in a facility close to Rogaška Slatina. Russian sturgeon was reared in Požeg water reservoir. Siberian sturgeon is cultivated in an aquaculture facility at Dvor in the Dolenjska region along the Krka River.

6.3 Croatia

According to Freshwater aquaculture report for EU Commission (EUMOFA 2021), aquaculture of sturgeon species in Croatia, or the production of caviar, was not reported for period 2009–2019.

7 Conclusions

According to Freidrich et al. (2018), conservation status of all sturgeon species in Europe has become critical without signs of recovery. Bearing this in mind, question about lack of previous action success should be made.

Sturgeons are fish group with characteristic traits, such as longevity, late maturation, spawning in freshwater (whether they are anadromous or potamodromous), and homing behavior, all of which require complex approach for their conservation. Since they move through different habitats for spawning, feeding, and wintering, they often undertake long migrations and cross borders. One of issues in sturgeon protection programs is lack of integrated cross-border management. Also, since sturgeons life cycle is long and fish mature late, only long-term protection/recovery programs over several decades could have chance for success. Without political will, lack of coordination, and clear responsibility, as well as lack of resources, successfully implementing any restoration program is futile. Although Action plan for sturgeon protection was developed in 2005. (Lenhardt et al. 2005b), its ratification and implementation are lacking.

Although the research of sturgeons is ongoing over a century, there is need for data update. Based on available data, during the mid-twentieth century, research of sturgeons in the Western Balkans was oriented to life history, biology, and ecology (Janković 1958; Ristić 1963a, b, c, 1967a, b, c, d, 1969a, b). Due to lack of different sturgeons species, as a consequence of Iron Gate dams construction, as well as lack of funding, later research was focused on sterlet morphometry, pollution assessment, and genetic (Jarić et al. 2011c; Lenhardt et al. 2012, 2014; Cvijanović et al. 2015, 2017), i.e., more laboratory-oriented research. In the last decade, development of population models and extinction models (Jarić et al. 2009a, 2010, 2014, 2016; Simić et al. 2014) provided tools for decision makers to adapt conservation measures. However, since the sturgeon environment is changing, and there is uncertainty about their response to these changes, more recent data should be available in order to have precise population assessment/simulation. Even knowledge about hybridization and identification could help avoid misidentification of species in wild, such as 2009. Sora and Mura rivers substitution of Siberian sturgeon for sterlet (Govedič and Friedrich 2018).

In Russia (around 1850), attempts for sturgeons artificial breeding were made, in order to maintain, restock, and enhance the wild populations (Carmona et al. 2009). With over a century of ex situ conservation efforts, this measure is still unavoidable action for sturgeon restoration, especially in Western Balkans. Although ongoing development of hatchery facility in Slovenia (as a part of LIFEBoat4sturgeons) should provide sterlets for restocking of Mura River, there is more need for development of ex situ sturgeon hatcheries. Most of the aquaculture facilities are commercially oriented, so the local government and authorities could encourage and help implement more ex situ conservation programs.

One of the things that are missing in all the countries of Western Balkans, due to lack of political commitment and funding, are monitoring programs. Apart from sporadic projects (i.e., MEASURES), there is no assessment of natural populations, distribution of endangered species, and evaluation of efficiency of implemented conservation measures.

Balkan region is the target of one of the most ambitious hydropower expansions plans in the world, with over the 2700 projects planned (Weiss et al. 2018). Despite the fact that the Balkan region has some of Europe's most pristine rivers and is a global hotspot for biodiversity, over one third of hydropower projects are located in protected areas (Weiss et al. 2018). If project of dams construction will materialize, it would have irreversible effects on water flow, as well as access to sturgeons spawning grounds. With lack of political will to deal with environmental protection issues in Western Balknas, long history of unsustainable sturgeon fishing and poaching, as well as increase in human population, urbanization and water pollution, only course of action is permanent conservation. In order to restore wild sturgeons in waters of Western Balkans, joint effort of all region countries is necessity. Otherwise, future generations wouldn't be able to know and admire these incredible creatures and will see their local common names as something of the past.

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