Species Status Assessment
for Russian, ship, Persian, and stellate sturgeon
(*Acipenser gueldenstaedtii*, *A. nudiventris*, *A. persicus*, and *A. stellatus*)

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Executive summary

We (the US Fish and Wildlife Service; Service) received a petition dated March 8, 2012 to list four sturgeon taxa as threatened or endangered under the U.S. Endangered Species Act of 1973, as amended (Act). These four taxa—Russian, ship, Persian, and stellate sturgeon (*Acipenser gueldenstaedtii*, *A. nudiventris*, *A. persicus*, and *A. stellatus*, respectively)—are large fish native to the Black, Azov, Caspian, and Aral Sea basins of eastern Europe and far western Asia. We refer to them collectively as the "Ponto-Caspian sturgeon," using the term for the Black, Azov, and Caspian region. On September 24, 2013 we made a substantial 90-day finding for all four Ponto-Caspian taxa (78 FR 58507).

This document is an evaluation of the present and future conservation status of Ponto-Caspian sturgeon and follows the Species Status Assessment (SSA) framework we developed for review of species' biology and extinction risk. We analyzed the best scientific and commercial data available on the status of the species and projected their status into the future under three alternative scenarios considering plausible future threats and conservation actions.

SSAs are science, not decision, documents. The listing decision will be made after reviewing the science in this document, along with all relevant statutes, regulations, and policies. The outcome of the decision process will be published in the Federal Register, and the public will have appropriate opportunities for commenting. The SSA report is intended to be updated as new information becomes available and to support relevant actions under the Act into the future.

Russian and stellate sturgeon were historically abundant across the Caspian, Black, and Azov Sea basins. Ship sturgeon is native to the Caspian, Black, Azov, and Aral Seas and their major rivers, while Persian sturgeon is only native to the Caspian basin. Each of the Ponto-Caspian sturgeon can live to between 30 and 60 years but begin reproducing only after six to 22 years, depending on the species and sex. Males spawn once every one-to-three years, but females require two to six years between reproductive bouts.

The Ponto-Caspian sturgeon reproduce in their natal rivers and large dams constructed in all the regions' rivers now block historic migration routes, severely limiting availability of spawning grounds. Moreover, since at least the 1500s, intensive fishing pressure, first for domestic meat consumption, later to fulfill international demand for caviar (unfertilized sturgeon eggs), has caused dramatic declines estimated by experts to have reduced each species' abundance by more than 95%.

In response to these declines, decades of regional- to global-scale legislative, law enforcement, and conservation breeding efforts have aimed to limit sturgeon harvest, regulate their trade [e.g., through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)], and restore their populations, but the effectiveness of these interventions has been limited, at best. The persistent impact of dams, corruption and poor performance within enforcement agencies, organized crime, international smuggling efforts, a lack of alternative livelihoods for some fishermen, and a robust black market for caviar have continued to put the Ponto-Caspian sturgeon at risk. These stressors have already caused the extirpation of Ponto-Caspian sturgeon from large portions of their historical ranges.

Meanwhile, from 1998 to at least 2018, the United States was the world's largest importer of sturgeon products (from the whole Acipenseridae family; primarily caviar, but also meat, skins, and chemical extracts). Although CITES requires specific labels documenting caviar origin, species, and permissions for international trade, it can be difficult to differentiate legal from illegal shipments as there now exists a black market for CITES labels themselves. Because of the nature of illegal trade, it is difficult to precisely quantify the scale of the illicit trade in caviar.

Dams and overfishing remain the major threats facing the species throughout their ranges. Lesser threats include large-scale loss of sturgeon prey due to an invasive ctenophore (comb jelly), water pollution, hybridization of wild fish with fish escaped from aquaculture facilities, fluctuating sea water levels, and climate change.

In SSAs, we use the concepts of resiliency, redundancy, and representation to gauge the current and future condition of the species. Resiliency is a population's ability to be self-sustaining and to withstand demographic and environmental variability (stochasticity); it is improved in large, connected populations. To determine the resiliency of each population of each species, we scored sturgeons' reproductive success and abundance, connectivity between feeding and spawning grounds, and habitat quality (especially water cleanliness and prey base). Highly redundant species have a large number of populations, which safeguards against rare, localized catastrophic events. Representation measures a species' capacity to adapt to changing environments.

At present, we do not consider any populations of any of the four taxa to be self-sustaining (Fig. ES1; Table ES1). In some locations, populations persist only thanks to continued restocking using captive-bred fish (which are then heavily fished). Despite the extensive population declines that have occurred, representation is moderate or even high for all four taxa; there remains either high intrapopulation genetic diversity (Russian sturgeon) or genetic differentiation among stocks in different rivers (ship, stellate, and Persian sturgeon).

We forecast the future condition of the Ponto-Caspian sturgeon for the year 2050 under each of three plausible scenarios for each focal river's population (Fig. ES1). Specifically, these scenarios included (1) a continuation of the current trajectory of threats and conservation measures, (2) an increase in proactive conservation measures across the region, and (3) targeted and more effective mitigation of dam impacts. Because we lack highly detailed, spatially explicit quantitative data on populations and their responses to local threats and conservation activities, we used qualitative projections based on threats, conservation measures, and the generally expected responses of sturgeon to the same.

TABLE ES1—HIGHLIGHTS OF CURRENT PONTO-CASPIAN STURGEON RESILIENCY, REDUNDANCY, AND REPRESENTATION	
Resiliency (Large, connected populations; reproducing and able to withstand demographic stochasticity)	• Few, if any, populations known to breeding at self-sustaining levels. • All four taxa are extirpated from upstream segments of most rivers due to river blockage by dams. • **Russian**: > 90% decline in the abundance of wild Russian sturgeon between 1964 and 2009; females—harvested for their roe—comprise only 10% of mature fish in major populations. • **Ship**: > 80% decline over the last three generations (24–66 years). • **Persian**: at least 80% decline over the last three generations (36–54 years). • **Stellate**: 92% decline from 1960s–2008.
Redundancy (number and distribution of populations to withstand catastrophic events)	• **Russian**: 10–12 populations extant, but all with low or very low resiliency. • **Ship**: 7 populations extant, but all with low or very low resiliency. • **Persian**: 2–5 populations extant, but all with low or very low resiliency. • **Stellate**: 9 populations extant, but all likely with low or very low resiliency.
Representation (Ecological and genetic diversity; maintenance of adaptive potential)	• **Russian**: High intrapopulation genetic variation, but low inter-population diversity. Extirpated from upstream segments of most inhabited rivers. • **Ship**: Extirpated from Aral Sea basin; freshwater population extirpated from Danube River; differentiated stocks remain in Caspian. • **Persian**: Differentiated stocks remain among south Caspian rivers. • **Stellate**: Differentiated stocks remain among Caspian rivers.

If the current trajectory of threats and conservation measures continues (a *status quo* future), we project continued declines in the condition of all four Ponto-Caspian sturgeon (Fig. ES1). Persian sturgeon may go extinct and the redundancy of Russian and ship sturgeon are expected to decrease strongly. Some species are likely to become extirpated from entire sea basins (e.g., Russian and ship sturgeon in the Azov), reducing the species' representation. No population is expected to be self-sustaining under this scenario.

If most range countries aggressively expand and improve the effectiveness of conservation measures (e.g., protection of existing stocks, implementation of CITES-recommended trade controls, and restocking practices) compared to those currently in place, there is the potential to improve the condition of many populations of all four Ponto-Caspian sturgeon taxa (Fig. ES1). Resiliency is projected to increase across-the-board, with some presently extirpated populations restored through restocking. Some populations (mainly in the Caspian basin) hold the potential to reach even high resiliency by 2050 under this scenario. Redundancy would very likely improve for each of the Ponto-Caspian sturgeon. Representation would likely increase under this scenario, as recovering populations slowly evolve new genetic variation.

If the only major conservation activity is to deploy improved engineering structures to facilitate sturgeon migration through and/or around dams, we project a slight blunting of the major declines in redundancy projected under the *status quo* scenario as some spawning grounds would become accessible again. Declines in representation may also be somewhat limited relative to those that occur in a *status quo* future. However, extirpations and declines in resiliency are still expected as fishing, any persisting dam impacts, and other threats would remain. Under this third scenario, Russian and ship sturgeon are likely to be in worse overall condition than at present, with only a small chance of slightly improved condition. Persian sturgeon could go extinct but is more likely to remain in a condition similar to its present status, as stellate sturgeon is projected to do.

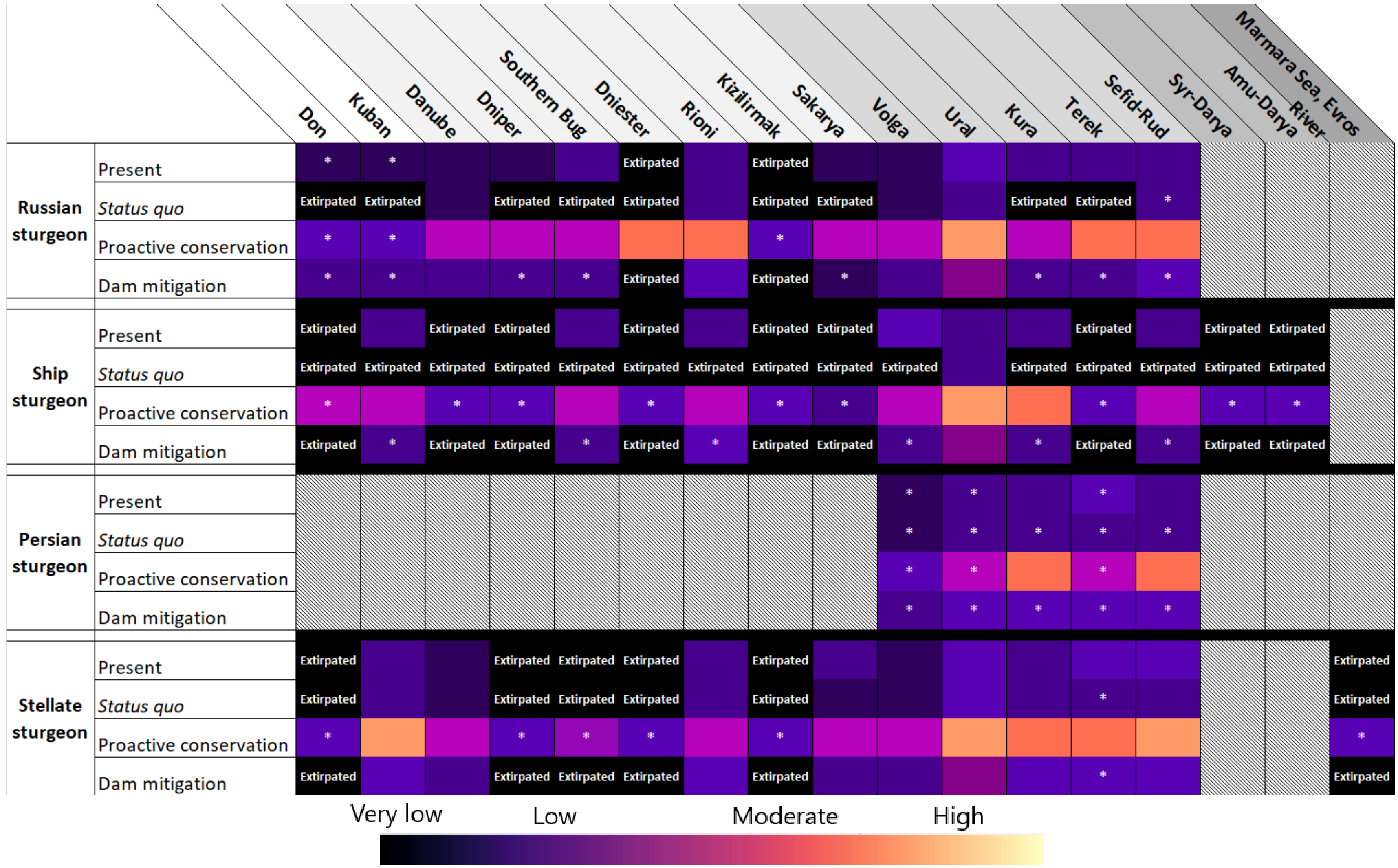


Figure ES1—Summary of resiliency for each of the four Ponto-Caspian sturgeon taxa in each focal river at present (top line for each taxon) and projected under each of three plausible future scenarios (lines 2 – 4 for each taxon). From left to right, rivers are grouped in the Azov, Black, Caspian, Aral, and Marmara Sea basins. An * indicates that there is uncertainty in whether a population is extant, or for future scenarios, whether it will be extant. Black-and-white striping indicates a river where the species does not occur and did not historically.

Acknowledgements

We thank Leonardo Congiu, Jörn Gessner, and Arne Ludwig of the IUCN Sturgeon Specialist Group, Fleur Scheele of Flora and Fauna International, and Beate Streibel-Greiter and Jutta Jahrl of World Wide Fund for Nature for providing valuable information on sturgeon biology and conservation. Sean Blomquist, Chief of the Branch of Delisting and Foreign Species, and members of the Branch provided guidance during this report's development.

The cover photo shows several smoked sturgeon for sale in a market in Astrakhan, Russia, along the banks of the Volga River. It is provided freely by Michael Clarke under a Creative Commons Attribution-Share Alike 2.0 license.

Chapter 1—Introduction

Sturgeon are large fish (family Acipenseridae) native to the temperate northern hemisphere (Billard and Lecointre 2001, p. 356). At the species level, they are most diverse in the Ponto-Caspian region, which includes the Black and Caspian Sea basins in eastern Europe and western Asia (Bemis and Kynard 1997, p. 180), where 7 of 27 species are found. Most sturgeon species have historically been heavily fished for meat and caviar—their unfertilized roe—and are subject other threats, including especially dam construction, which hinders connectivity along migration routes between feeding to spawning grounds (Billard and Lecontre 2001, pp. 380–385).

We were petitioned March 8, 2012 to list four sturgeon taxa—Russian, ship, Persian, and stellate sturgeon (*Acipenser gueldenstaedtii*, *A. nudiventris*, *A. persicus*, and *A. stellatus*, respectively—from the Ponto-Caspian and adjacent Aral Sea regions as endangered under the U.S. Endangered Species Act ("Act"). These four taxa were included as part of a larger petition for 15 sturgeon species originally delivered to the National Marine Fisheries Service, but were later determined to fall within our jurisdiction. On September 24, 2013 we made a substantial 90-day finding for all four Ponto-Caspian taxa (78 FR 58507). The remaining 11 species are not assessed as part of this report.

For the purposes of this report, we refer to the four taxa assessed here (*A. gueldenstaedtii*, *A. nudiventris*, *A. persicus*, and *A. stellatus*) as the "Ponto-Caspian sturgeon." The four Ponto-Caspian sturgeon are assessed together in this Species Status Assessment (SSA) because their shared geographies, related life histories, and exposure to very similar threats allow efficiency of review.

Species Status Assessments (SSAs) are written to inform the decisions under the Act (e.g., whether or not to list a species as threatened or endangered, but also whether to delist, up-, or down-list a species) and use the concepts of resiliency, redundancy, and representation to gauge the current and future condition of the species. Resiliency is a population's ability to be self-sustaining and to resist demographic stochasticity; it is improved in large, connected populations. Highly redundant species have a large number of populations, and representation is a measure of the species' capacity to adapt to changing environments, which is improved by high genetic variability and the use of diverse habitats. SSAs are intended to be updated as new information becomes available and to support relevant actions under the Act into the future.

The SSA framework (Smith et al. 2018, entire) consists of a review of the species' biology and its conservation status considering the threats and protective measures facing it. We project the status of the species into the future under alternative threat and conservation scenarios and given the conditions needed to maintain viability.

The SSA is not a decision document and does not lead directly to our decision on whether to propose listing of the species under the Act. Rather, the SSA is a review of the available information strictly related to the conservation status of the focal species. The listing decision will be made after reviewing the science in this document and all relevant statutes, regulations, and policies. The outcome of the decision process will be published in the Federal Register, and the public will have appropriate opportunities for commenting. Because both readers and decision-makers inherently have variable levels of risk tolerance, in Appendix I we calibrate the likelihood statements used throughout the text to help standardize discussion of uncertainty, which is an inherent part of any scientific investigation.

Chapter 2—Biology of the species

Taxonomy and evolutionary history

Sturgeon are most closely related to the paddlefish (Polyodontidae; Billard and Lecointre 2001, pp. 356 & 362). Together, these two fish families are the modern members of an evolutionarily basal group (Acipenseriformes) that diverged from other ray-finned fish (Actinopterygii) at least 200 million years ago (Du et al. 2020, p. 1; Billard and Lecointre 2001, p. 362). For reference, this split between Acipenseriformes and Actinopterygii occurred around the time in the late Triassic or early Jurassic period when the first mammals diverged evolutionarily from the reptile lineage (Kemp 2005, pp. 2–3).

All four Ponto-Caspian sturgeon are valid entities for listing under the Act (Table 2.1). Russian, ship, and stellate sturgeon are all full species (ITIS 2020, not paginated; Fricke et al. 2019, not paginated). Persian sturgeon was considered a subspecies of Russian sturgeon until 1973 when it was separated based on morphological, immunological, and behavioral characteristics (Lukyanenko and Korotaeva 1973 cited in Gessner et al. 2010c, not paginated). As of 2020, ichthyological and general taxonomic authorities continue to list Persian sturgeon a separate species (ITIS 2020, not paginated; Fricke et al. 2019, not paginated; Esmaeli et al. 2018, p. 7; Çiçek et al. 2015, p. 143). However, the issue is not completely settled and one study found that morphologic and genetic characteristics of 53 individuals did not support separation of Persian and Russian sturgeon (Ruban et al. 2011, throughout). A larger, range-wide study may help settle the issue more firmly (Gessner et al. 2010c, not paginated). Regardless, even subspecies can be listed, per section 3(16) of the Act.

Table 2.1—Taxonomy of the four sturgeon species assessed in this report and valid synonyms (Fricke et al. 2019, not paginated; ITIS 2020, not paginated). Degenerate (disused) synonyms are not included.

Common name	Latin name, taxonomic authority
Russian sturgeon	*Acipenser gueldenstaedtii*, Brandt and Ratzeburg 1833
Ship sturgeon	*A. nudiventris*, Lovetsky 1828
Persian sturgeon	*A. persicus*, Borodin 1897
Stellate sturgeon	*A. stellatus*, Pallas 1771

Naturally produced interspecific sturgeon hybrids can compose a small portion of juveniles in the wild (up to 3.1% in the Volga River, the Caspian's biggest inlet, between 1965 and 1995); whether these hybrids mature and reproduce is unclear (Billard and Lecointre 2001, p. 363). Many different hybrids have been produced through aquaculture by combining pairs of the four taxa assessed here, along with beluga sturgeon (*Huso huso*), sterlet (*A. ruthenus*), and green sturgeon (*A. medirostris*; Billard and Lecointre 2001, p. 363).

Physical description

All sturgeon have an elongate body form with a flattened underside and downward-facing mouth (Fig. 2.1). As adults, their bodies are at least partially covered with bony plates and they have tactile barbells hanging beneath the snout (Billiard and Lecointre 2001, p. 363). Sturgeon have small eyes—characteristic of species that live in their low-light river- and lake-bottom habitats—and a cartilaginous skeleton (Billiard and Lecointre 2001, p. 363). Specific morphological differences among Acipenseridae species are described in Billiard and Lecointre (2001, entire) and in the references within the sturgeon family account in Fricke et al. 2019. Adult Ponto-Caspian sturgeon (pictured in Fig. 2.1) attain sexual maturity at around 1 m in length, but can grow to be 2–2.4 m long and to weigh 70–120 kg (Table 2.2; Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated).

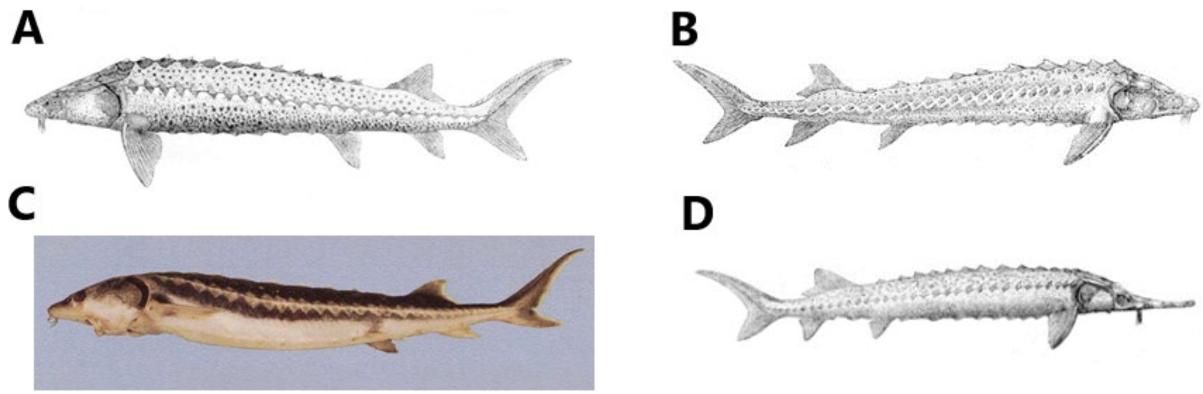


Figure 2.1—The four taxa assessed in this report. (A) Russian, (B) ship, (C) Persian, and (D) stellate sturgeon [A, B, D from Heckel and Knur 1858, p. 343–349; C reproduced under Creative commons CC1.0 public domain license (A. Abdoli)].

Geographic setting

The Ponto-Caspian sturgeon are native to over 20 countries in the Black, Azov, Caspian, and Aral Seas, and their rivers (Figures 2.2–2.9; Table 2.2; Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated). Among the world's largest inland waterbodies (Kostianoy et al. 2005, p. 1; Kideys 2002, p. 1482), the Black and Caspian Seas are fed by major rivers including Europe's two longest—the Danube, which flows from Germany to Romania and into the Black Sea, and the Volga, which runs 3500 km through western Russia into the Caspian. The Caspian basin is said to have contained over 90% of the world's sturgeon biomass (Caspian Environment Programme 2002, p. 17), although we are not aware of data firmly backing this claim.

The Volga contributes 82% of freshwater discharge to the Caspian (Dumont 1995, p. 674) and formerly accounted for 75% of sturgeon harvest in the Caspian Sea, primarily Russian and stellate sturgeon, but also fewer ship and Persian sturgeon (Ruban and Khodorevskaya 2011, p. 202; Lagutov and Lagutov 2008, p. 201). Together, discharge from the Danube, Dnieper, and Dniester Rivers accounts for about 85% of water entering the Black Sea (Sorokin 2002 cited in Kideys 2002, p. 1482).

Table 2.2—Key characteristics of Russian, ship, Persian, and stellate sturgeon.

	Russian sturgeon	**Ship sturgeon**	**Persian sturgeon**	**Stellate sturgeon**
Major basins	Azov, Black, and Caspian Sea basins	More common historically in Caspian and Aral than Black, Azov Sea basins	Caspian basin, esp. its southern extent	Azov, Black, and Caspian Sea basins
Countries (extirpated from *italicized* countries; introduced and established to underlined ones)	Armenia; *Austria*; Azerbaijan; *Belarus*; *Bosnia & Herzegovina;* Bulgaria; *Croatia*; *Hungary*; Georgia; *Germany*; Iran; Kazakhstan; Moldova; Romania; Russia; Serbia; *Slovakia*; Turkey; Turkmenistan; Ukraine	*Armenia;* Azerbaijan; *Bosnia & Herzegovina*; *Bulgaria*; China; *Croatia;* Georgia; *Hungary*; Iran, Kazakhstan; *Moldova;* Russia; *Romania*; *Serbia;* Turkey; Ukraine; *Uzbekistan*; *Turkmenistan*	Armenia; Azerbaijan;; Iran; Kazakhstan; Russia; Turkmenistan;;	Armenia; *Austria*; Azerbaijan; *Belarus*; *Bosnia & Herzegovina;* Bulgaria; *Croatia*; *Hungary*; Georgia; *Germany*; Iran; Kazakhstan; Moldova; Romania; Russia; Serbia; *Slovakia*; Turkey; Turkmenistan; Ukraine
Age at maturity, years (♂/♀)	8–13/10–16	6–15/12–22	8–15/12–18	6–12/7–14
Generation time, years	10–16	12–22	12–18	8–14
Length at maturity, cm (♂/♀)	100/120	Unknown; likely ~1m	122/162	105/120
Weight at maturity, kg (♂/♀)	3/9	Unknown; likely 3–20 kg	12/19	3–4/9–10
Reproductive frequency, years (♂/♀)	2–3/4–6	1–2/2–3	2–4/2–4	2–3/3–4
Maximum longevity (years)	>50; rarely reaches 40 today	32	60–70; rarely reaches 40 today	41; rarely reaches 30 today
Fecundity / female	350,000	400,000–850,000	320,000	Up to 1.5 million
Maximum size	100 kg; 230 cm	127 kg; 200 cm	70 kg; 240 cm	80 kg; 220 cm

WWF 2012, not paginated; Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated; Lagutov and Lagutov 2008, p. 200; Billard and Lecointre 2001, pp. 357–360; Putilina and Artyukhin 1985 cited in Khoshkholgh et al. 2013; WSCS and WWF 2018, p. 41.

Data as given, without indication of whether these are averages, medians or otherwise, and without sample size or measures of variability.

Russian sturgeon are native to the rivers that flow into the Azov Sea (including the Don and Kuban), the Black Sea (including the Southern Bug, Danube, Dnieper, Dniester, Kızılırmak, Sakarya, and Rioni) and the Caspian Sea (including the Kura, Terek, Ural, Sefid-Rud, and

Volga; Billard and Lecointre 2001, p. 373). They are extirpated from the northern and far western extents of most of these rivers (Figs. 2.2 & 2.5; Gessner et al. 2010a, not paginated).

Ship sturgeon were historically more common in the Caspian and Aral Sea basins than the Black and Azov Sea basins (Billard and Lecointre 2001, p. 371). In contrast to Russian and stellate sturgeon which formed the bulk of sturgeon biomass in the hugely productive Volga River, the Ural River was historically ship sturgeon's stronghold (Lagutov and Lagutov 2008, p. 201), with considerable populations in Azerbaijan's Kura River in the southwestern Caspian, too (Aladin et al. 2018, p. 2069). The species is extirpated from the Aral Sea and its two main rivers, the Amu-Darya and Syr-Darya (Zholdasova 1997, pp. 374–378).

Persian sturgeon are native only to the Caspian Sea basin and were most abundant in the Sea's south (Gessner et al. 2010c, not paginated). Thus, although they ascend the Volga and Ural Rivers, they historically comprised a larger proportion of the sturgeon community in the Terek, Kura, and Sefid-Rud Rivers, and in smaller watercourses in Azerbaijan and Iran (Billard and Lecointre 2001, p. 374).

Stellate sturgeon have a widespread historical range very similar to that of Russian sturgeon; they are native to the Black, Caspian, and Azov seas, and the rivers that flow into them. Also, like Russian sturgeon, they are extirpated from the upstream reaches of the Volga, Danube, Dniester, and Dnieper Rivers, as well as the Kura River (Figs. 2.4 & 2.8; Gessner et al. 2010c). Unlike Russian sturgeon, stellate sturgeon formerly had a population in the Evros River and the Sea of Marmara, immediately southwest of the Black Sea (Suciu and Qiwei 2010, not paginated; WSCS and WWF 2018, pp. 10–12 & pp. 41–42).

Each of Russian, ship, and stellate sturgeon were formerly found far up the Danube River, the main tributary of the Black Sea. For instance, ship sturgeon were formerly found as far north as Bratislava, Slovakia and some of these fish spent their full lives in freshwater, without the breeding migration to a saltwater sea typical of most sturgeon (WSCS and WWF 2018, p. 35; Billard and Lecointre 2001, p. 371). Although the three native Ponto-Caspian taxa are now extirpated from the Danube's upstream reaches, their abundance was always highest near the river's mouth and decreased moving upstream (Friedrich et al. 2019, p. 1060).

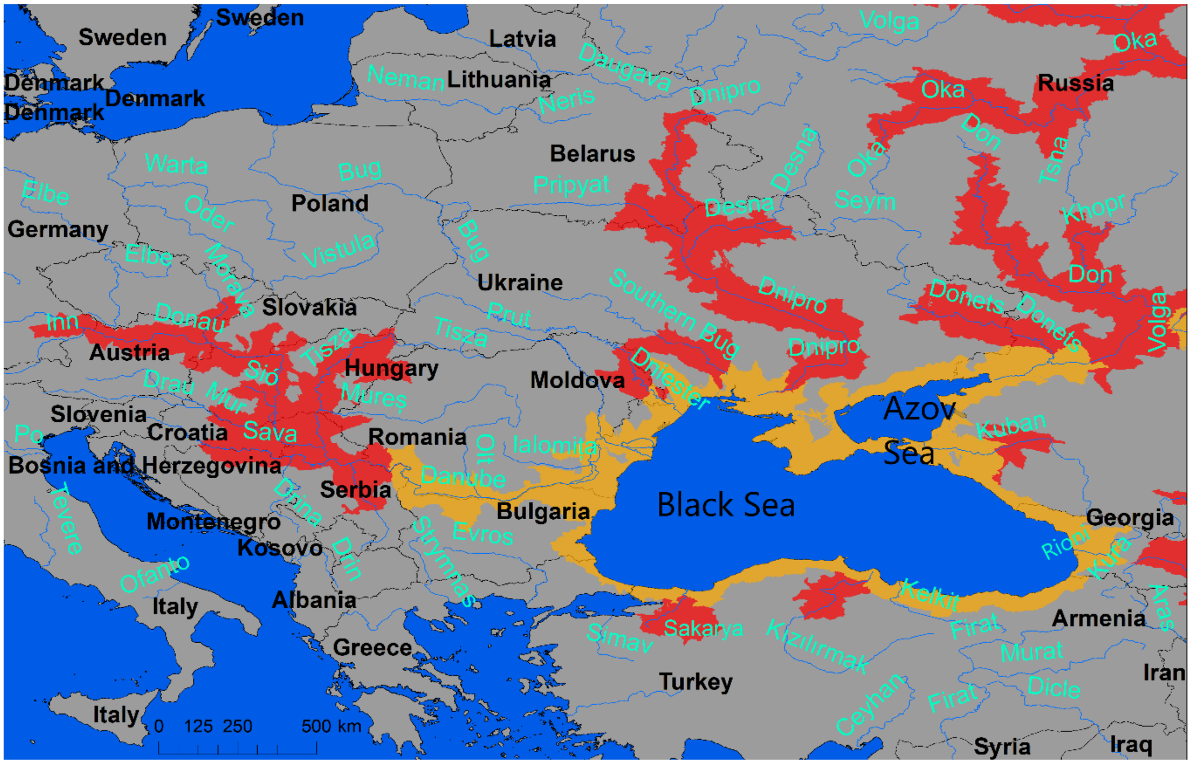


Figure 2.2—Russian sturgeon range in the Black Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010a (not paginated).

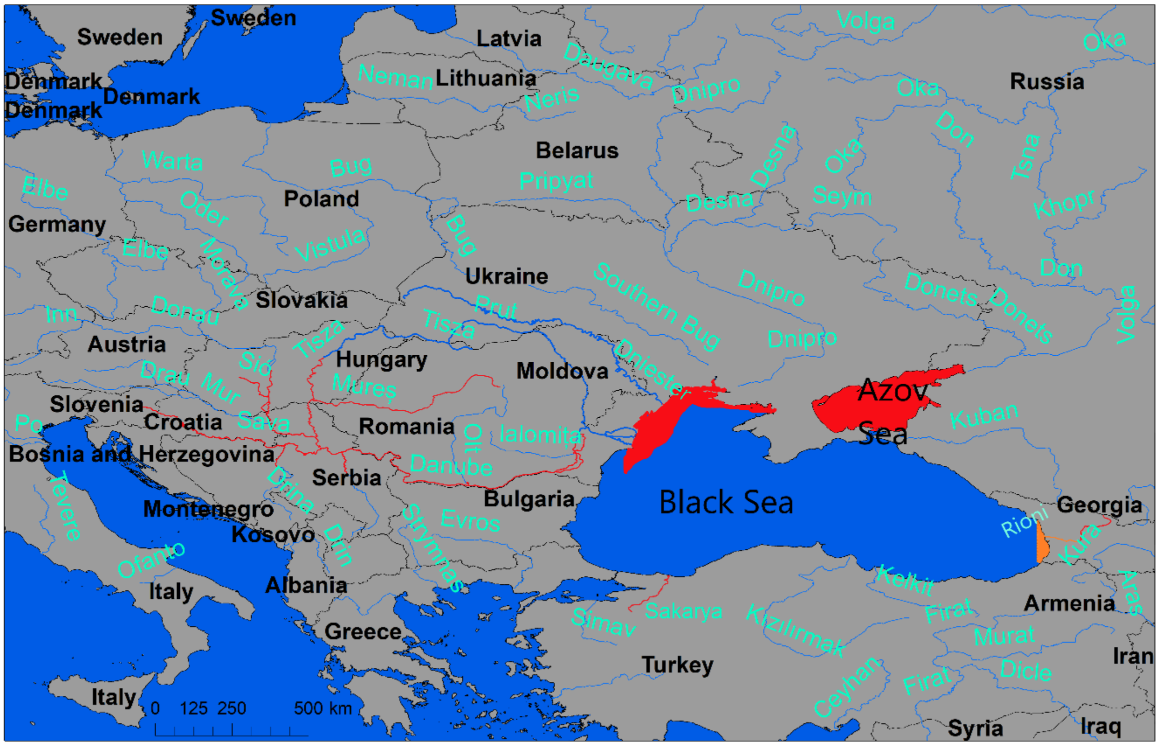


Figure 2.3—Ship sturgeon range in the Black Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010d and adapted based on personal communication with F. Scheele, Flora and Fauna International, March 26 and April 17, 2020. This communication indicated the species is extant and breeding in the Rioni River at the eastern edge of the Black Sea in Georgia.

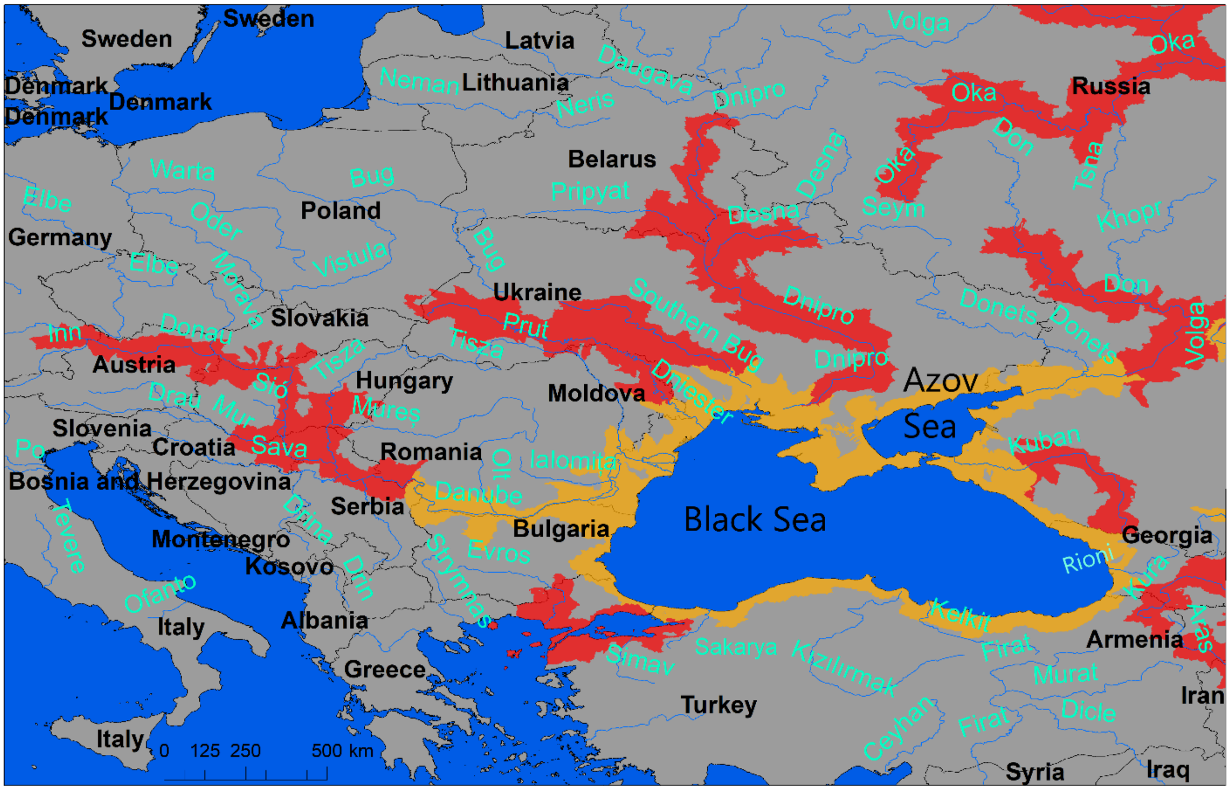


Figure 2.4—Stellate sturgeon range in the Black Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010c (not paginated).

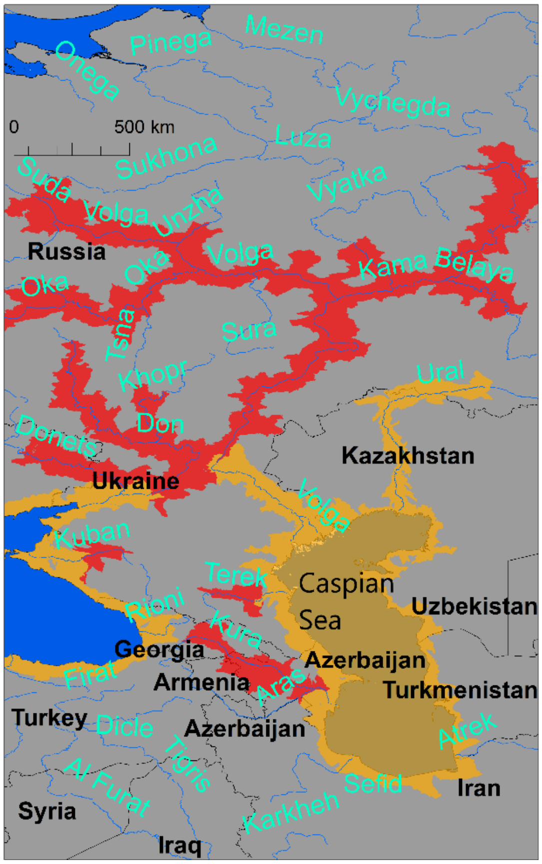


Figure 2.5—Russian sturgeon range in the Caspian Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010a (not paginated). The eastern Black Sea is visible in the lower left.

Figure 2.6—Ship sturgeon range in the Caspian Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010d. The species is present but not breeding in the Sefid-Rud River (Council of Europe 2018, pp. 35). The eastern Black Sea is visible in the lower left.

Figure 2.7—Persian sturgeon range in the Caspian Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010b (not paginated). The eastern Black Sea is visible in the lower left.

Figure 2.8—Stellate sturgeon range in the Caspian Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010c (not paginated). The eastern Black Sea is visible in the lower left.

Figure 2.9—Ship sturgeon range in the Caspian Sea basin. Red indicates regions from which the species is extirpated. Distribution data from Gessner et al. 2010d.

Habitat, reproduction, and development

All four Ponto-Caspian sturgeon taxa use both rivers and seas (Billiard and Lecointre 2001, pp. 371–374). Adults live and feed in saline seas, but migrate several hundred km upstream into rivers to spawn. In particular, sturgeon return to breed in the same river they were born (Lagutov and Lagutov 2008, p. 197). A small number of populations, especially of ship sturgeon, live only in freshwater (WSCS and WWF 2018, p. 35; Billard and Lecointre 2001, p. 371).

Adult stellate sturgeon inhabit water anywhere from 50–300 m deep, but will use water as little as 3 m deep in the shallow northern Caspian Sea (Billard and Lecointre 2001, p. 374). They are rarely found in turbulent estuaries, instead favoring calm rivers and coasts (Billard and Lecointre 2001, p. 374). Ship sturgeon prefer shallower water, especially along coasts (Fig. 2.6; Billiard and Lecointre 2001, pp. 371–372).

Adult Ponto-Caspian sturgeon migrate into rivers in the spring or fall (Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated), then spawn in late spring. Spawners that migrate in fall overwinter in their river before spawning. In Russian sturgeon, fall migrants travel 900–1200 km up the Ural River, compared to spring spawners which go 320–650 km (Gessner et al. 2010a, not paginated). Because they tend to travel farther upstream, they may be reproductively separated from spring migrants (Gessner et al. 2010a–c, not paginated), although the degree of any such separation is not well established (e.g., how consistent is spring vs. fall migration within a lineage). Among spring-spawning stellate sturgeon, males remain at the spawning site for up to six weeks, whereas females will only stay 10–12 days. Immediately after spawning, adults return to the sea (Suciu and Qiwei 2010c, not paginated).

If water conditions are not correct (temperature, flow, depth, low turbidity, and lack of pollution), females will fail to lay eggs (Ruban et al. 2019, p. 389; Chebanov et al. 2011 cited in Friedrich et al 2019, p. 1060). Water temperatures, in particular, are key to spawning success. Russian, ship, and stellate sturgeon all prefer water of 8–16°C (Gessner et al. 2010a, not paginated; Gessner et al. 2010b, not paginated, Suciu and Qiwei 2010, not paginated), whereas Persian sturgeon breed beginning at 16°C and stop at 25°C (Gessner et al. 2010c, not paginated). Thus, Persian sturgeon begin spawning around April, but pause spawning in the south of their range where waters become too warm in the summer (Gessner et al. 2010c, not paginated).

Eggs just a few mm in diameter are deposited in gravelly or sometimes sandy river bottoms where females and males must spawn near-simultaneously because sperm are diluted by water currents and are only viable for a few minutes (Billard and Lecointre 2001, p. 360). Cool, flowing water is necessary to oxygenate the eggs and to avoid sediment accumulation (Lagutov and Lagutov 2008, p. 232). Ponto-Caspian sturgeon spawn at sites with water between 2 and 25 m deep (Billard and Lecointre 2001, p. 361) and depending on the species, a 50 kg female will lay from a few hundred-thousand to 1.5 million eggs. Stellate sturgeon have the highest fecundity among the Ponto-Caspian sturgeon and ship sturgeon's is lowest, although similar to that of Russian and Persian sturgeon (Table 2.2; Billard and Lecointre 2001, p. 360).

Once eggs hatch (approximately 8–11 days post-spawning, dependent on the species; Billard and Lecointre 2001, p. 360), larva drift downstream while surviving off their remaining yolk sack (2–3 days in stellate sturgeon; up to 8 days in other species; Billard and Lecointre 2001, p. 360). Fry then begin feeding and juveniles tend to use shallower areas than adults (Gessner et al. 2010b, not paginated). Juvenile Russian sturgeon can remain in their natal river for as long as four years before reaching the sea (Khodorevskaya et al. 2009 cited in Ruban et al. 2019, p. 389). Other sturgeon may spend only their first year in the river (Lagutov and Lagutov 2008, p. 199).

Sturgeons' high fecundity is balanced by very high mortality of early life stages. For some sturgeon, no more than 1 in 2000 fish survive their first year (Jaric and Gessner 2013, p. 485–486; Jager et al. 2001, p. 351); similar numbers are likely for the taxa assessed here. Juvenile and adult sturgeon have much higher natural survival rates (20–90% per year for several *Acipenser* spp.; Jaric and Gessner 2013, p. 485–486; Jager et al. 2001, p. 351), although older fish are heavily harvested for their roe, sold as caviar (see *Chapter 3*; Van Eenennaam et al. 2004, p. 302).

Sturgeon continue to grow and reach sexual maturity after 6 to 22 years (Table 2.2). Males mature one to a few years earlier than females (Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated). Most female sturgeon spawn every 2–4 years, although Russian sturgeon females may wait up to 6 years between spawning bouts (Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated). Sturgeons' long times to maturity and intervals between reproductive bouts limit their capacities to rebound from population declines.

Diet

Adult sturgeon eat small fish, mollusks, worms, and crustaceans (Billard and Lecointre 2001, p. 373; Polyaninova and Molodtseva 1995 cited in Billard and Lecointre 2001, p. 374). In the Caspian and Black Sea regions, this includes herring (Clupeidae), gobies (Gobiidae), crabs (Brachyura), mysids (Mysidae), annelids, and other taxa (Gessner et al. 2010a–c, not paginated; Suciu and Qiwei 2010, not paginated).

Population biology

Population modeling (Jaric et al. 2010, pp. 219–227) indicates that viability of Ponto-Caspian sturgeon populations is highly sensitive to:

- abundance of adult females in a population;
- adult sex ratio in the population;
- age of females at first reproduction;
- female fecundity (number of eggs laid);
- natural mortality rate of the youngest age classes;
- spawning frequency of females;
- and natural mortality rate of adults.

The population structure (i.e., which groups of conspecifics breed together) of Ponto-Caspian sturgeon is best-studied in stellate and Persian sturgeon from the Caspian Sea. These taxa each very likely have separate populations that travel up and spawn within different rivers (Norouzi and Pourkazemi 2016, pp. 691–696; Norouzi et al. 2015, pp. 96–99; Khoshkholgh et al. 2013, pp. 33–35). This is reasonable because sturgeon return to breed in their natal river (Gessner and Ludwig 2020, pers. comm.; Pikitch et al. 2005, p. 243). Fewer studies of population biology have been completed for Russian and ship sturgeon and in the Black, Azov, and Aral Sea basins, but we assume similar patterns. We therefore assess and summarize the status of the four Ponto-Caspian sturgeon taxa within each of the major rivers that they presently inhabit or historically inhabited and consider rivers as populations, the analytic units of our status assessment.

Nonetheless, some data (e.g., some fisheries landing records) are recorded for entire sea basins. In the absence of finer scale data, we are forced to use these coarser records, despite knowledge that they very likely include fish from greater than one population. Similarly, some authors indicate distinct populations within rivers, delineated by their winter or spring migration (Friedrich et al. 2019, p. 1060), but this separation and its frequency across rivers is uncertain.

Three Rs

Based on the life history described above, the demographic and habitat requirements of Ponto-Caspian sturgeon at the individual, population, and species levels are summarized in Table 2.3. We consider these needs in the context of the 3Rs to determine the condition of the species at present and for three plausible future scenarios in Chapters 4 and 5.

We assign numerical resiliency scores to each analysis unit considering the in-depth discussion in Chapters 3 and 4 of each unit's condition. In particular, we consider three criteria to characterize the resiliency of populations: sturgeon reproductive success and abundance, habitat quality to support prey availability and sturgeon health, and the connectivity of spawning and feeding grounds. Table 2.4 details the specifics for scoring each criterion and we summed the point values to obtain overall resiliency scores for each analysis unit.

Reproductive success and abundance are combined into a single criterion because we found it is common to be lacking information on one of the two for a given population, and especially to be without good abundance data. Still, we did not want to fully exclude the use of abundance data from resiliency scoring, where we were able to include it. Therefore, the criterion is primarily based on reproductive success, but highly abundant populations can be scored as more resilient. We also allowed twice as many points for the reproductive success and abundance criterion compared to the other two criteria because a population cannot be resilient if it is not reproducing, regardless of connectivity and habitat quality.

Table 2.3—Demographic and habitat requirements of Ponto-Caspian sturgeon individuals, populations, and species.

Individual	Population	Species
Clean, unpolluted water in spawning and feeding ranges	Connectivity of feeding and spawning grounds; usually several hundred km or more up the natal river for upstream (spawner) and downstream (spawner and larval/juvenile) migration.	Adaptive capacity (genetic and/or ecological variation) to respond ecologically and/or evolutionarily to changing environments; partially related to population size
Well-oxygenated, low-turbidity water for respiration, including by eggs on spawning grounds.	Gravel (preferable) or sand substrates 2–25 m below the surface for spawning.	Distinct and/or wide-ranging populations (e.g., spawning in multiple rivers) to reduce susceptibility to catastrophic disturbances.
Abundant prey (larval insects, small mollusks, crustaceans, & fish) in feeding and spawning grounds at appropriate time of year	Survival to reproductive age and for the several years between reproductive bouts.	
	Water of suitable temperature and flow rate for spawning and development; approximately 8–16 °C and 1–1.5m/s, but 16–25 °C for Persian sturgeon, specifically.	
See citations in the main text for all needs listed.		

We considered total scores to indicate the following levels of resiliency:

- 4 and lower: very low resiliency;
- greater than 4 and less than 7: low resiliency
- 7 to 10: moderate resiliency;
- greater than 10: high resiliency.

The maximum possible resiliency is 12.

Risk tolerance varies from person to person. Therefore, we further define our language regarding resiliency. High-resiliency units either have the highest possible scores for connectivity and habitat quality and are at least more likely than not to be reproducing at a self-sustaining level, or are highly abundant and reproducing at or above the self-sustaining level with at least moderate connectivity and habitat quality. There is unlikely to be strong evidence that moderately resilient units they are reproducing at a self-sustaining level and they are likely experience at least moderately impaired connectivity and habitat quality. Low- and very low-resiliency units are, at best, breeding but not likely to be self-sustaining, due to ongoing conservation threats; such populations exist with severely limited connectivity and habitat quality and may become extirpated, perhaps rapidly in the case of very low-resiliency units.

The redundancy of each species is directly related to the number of extant populations; with a greater number of populations, especially geographically dispersed ones, the species is better able to withstand local, rare, catastrophic events. However, redundancy is interrelated with resiliency; low-resiliency populations cannot be considered to contribute to redundancy to the same degree, or with the same level of future certainty, as more resilient ones. We therefore scored redundancy as the number of moderate- or high-resiliency populations plus one half the number of very low- and low-resiliency populations. To project possible future redundancy, we consider which populations are likely to persist, to be extirpated, or to be restored. We consider representation in light of the genetic diversity and integrity (i.e., lack of hybridization) of a species, as well as the range of habitats it occupies.

Because there can be uncertainty in when to consider a population extirpated, we defined this condition. Specifically, we considered a population to be currently extirpated if the best available information indicate no record of the species for at least 10 years, a time period similar in length to a one short generation for all four Ponto-Caspian taxa (Table 2.2). Alternatively, in the absence of temporal information on the time since a population was last confirmed to be extant, we also called a population extirpated if an authoritative source on the population reported it as extirpated and we did not find more recent evidence to the contrary. For projections of future condition, we considered a population extirpated when it received a score of 0 in the reproductive success and abundance criterion.

Table 2.4. Resiliency criteria.

Resiliency criteria	Scoring
Reproductive success and abundance	High: 6 points where evidence indicates adequate offspring are produced for the population to be self-sustaining given current mortality (natural and anthropogenic) and the species is highly abundant; Medium: 4 points if present and breeding most or all years, with evidence the population is at least more likely than not to be self-sustaining, given current threats; Low: 2 points if present and breeding, but at least likely not to be self-sustaining, given current threats; Very low: 1 point if present but at least likely not to be breeding (including but not limited to populations persisting only due to restocking of juvenile fish); Extirpated: 0 points for an extirpated population.
Connectivity between spawning and feeding grounds	High: 3 points for no barriers to connectivity. Medium: 2 points for barriers to connectivity only well upstream, allowing access to most of the river's length. Low: 1 point for barrier(s) to connectivity removing access to most or all of the river's length.
Habitat quality to support prey availability and sturgeon health	High: 3 points for high habitat quality enabling abundant food resources and creating no known threats to fish health. Medium: 2 points for moderate habitat quality, at least as likely as not to be impacting sturgeon health and the abundance of food resources. Low: 1 point for poor habitat quality at least very likely to be causing strong negative impacts on sturgeon health and food resources.

All the above criteria are theoretically interesting but what about the practice? I sincerely doubt that reliable and suitable information can be collected from the different populations at this level of detail.

Chapter 3—Threats and conservation measures

Dams and other water control engineering

Nearly 100 dams at least 8 m tall are present in the Caspian and Aral Sea Basins, and approximately 300 dams dot the Black and Azov Sea basins (Fig. 3.1; GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502). Most were constructed to supply water for drinking, irrigation, and industry, although many of the very largest are hydroelectric power plants (Fashchevsky 2004, p. 192). All four of the Ponto-Caspian sturgeon have lost access to spawning habitat due to dam and reservoir construction (Fig. 3.1, 3.2; GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502; Lagutov and Lagutov 2008, p. 196; Fashchevsky 2004, p. 184). The several major challenges dams present for sturgeon are listed below (WSCS and WWF 2018, p. 48; He et al. 2017, p. 12 and references therein; WWF 2016, p. 19; Fashchevsky 2004, p. 185).

- Dams prevent sturgeon from migrating upstream to their natal spawning grounds;
- Hydroelectric dam turbines can grind downstream-migrating fish to death;
- Gravel is retained behind dams and cannot reach downstream spawning habitats, degrading their quality;
- Where upstream migration is possible, fish can be trapped upstream of dams without sufficient food resources and habitat after spawning (adults) and hatching (larva and juveniles);
- Without water flow to cue on, fish in relatively stagnant upstream reservoirs may be unable to orient for downstream migration;
- Reservoirs upstream of dams tend to accumulate relatively polluted, low-oxygen, high-sediment water that reduces sturgeon health and reproductive success;
- Surface waters of dam reservoirs have higher temperatures, potentially increasing energy demands of downstream-drifting larva still reliant on yolk sac reserves;
- Managed water level changes can trigger incorrectly timed and less-successful migrations and spawning.

All major rivers in the Ponto-Caspian region are dammed (Figs. 3.1 & 3.2; GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502; Lagutov and Lagutov 2008, p. 196). Fewer than 2000 hectares of spawning habitat remained in the Caspian's major rivers as of 2008, with about 75% of this in the Volga and Ural (Lagutov & Lagutov 2008, p. 230). About one sixth of the existing spawning habitat is in rivers where sturgeon failed to spawn for at least 25 years (Lagutov & Lagutov 2008, p. 230) and we found no evidence there has been any expansion of spawning area since then.

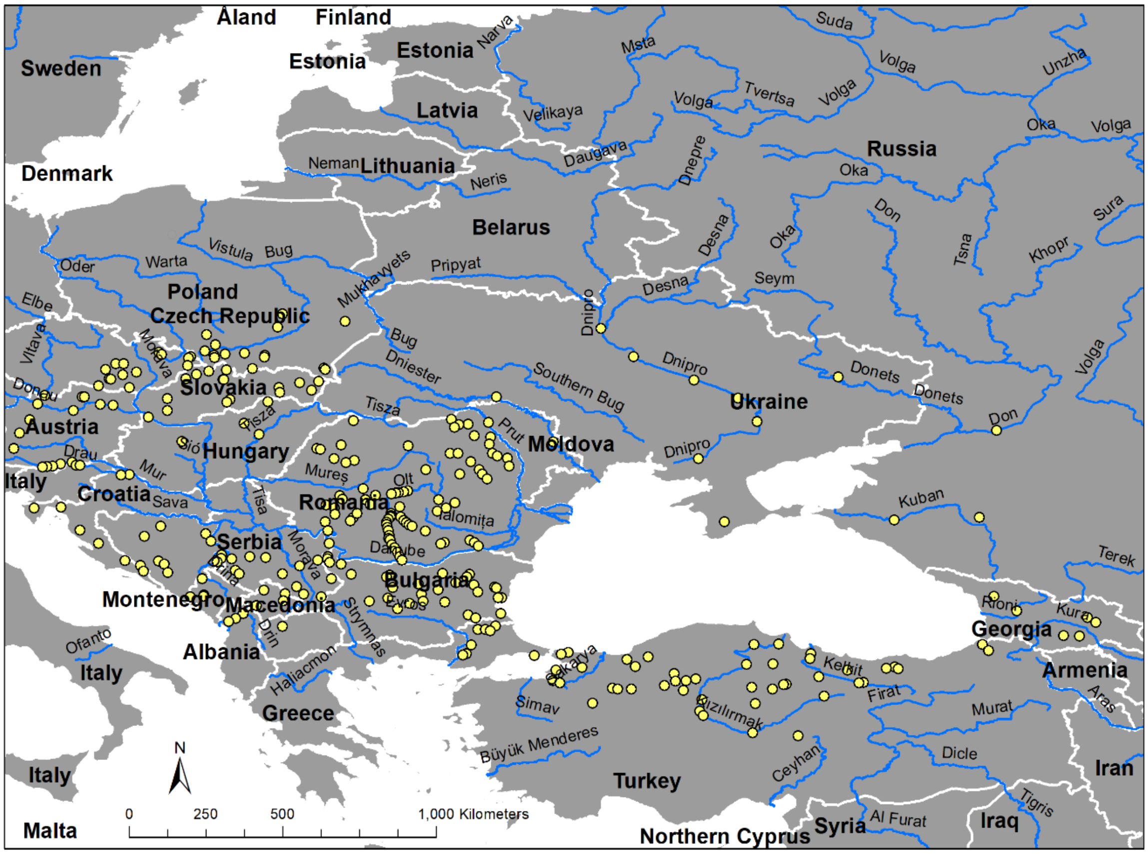


Figure 3.1—Dams (yellow dots) in the Black and Azov Sea basins. Data from GRanD 2019 (not paginated) and Lehner et al. 2011 (pp. 494–502). These databases are not complete; they are best for large dams (reservoir size ≥ 0.1 km^3 and/or dam height ≥ 15m). Dams shown without rivers are located on smaller watercourses not mapped here. Dams on rivers that flow into the Baltic, Caspian, and Mediterranean Seas (e.g., Volga and Ofanto Rivers) are not shown on this figure.

Figure 3.2—Dams (yellow dots) in the Caspian and Aral Sea basins. Data from GRanD 2019 (not paginated) and Lehner et al. 2011 (pp. 494–502). These databases are not complete, but are best for large dams (reservoir size ≥ 0.1 km^3 and/or dam height ≥ 15m). Dams shown without rivers are located on smaller watercourses not mapped here. Dams on rivers that flow into the Black and Azov Sea (e.g, Kuban River) are not shown on this figure.

As the foremost example, the Volgograd Dam was built on the Volga River between 1958 and 1961 (Ruban and Khodorevskaya 2011, p. 204). It is now the final dam of about 10 that impede the flow of the Volga and its tributaries to the Caspian Sea (GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502; Figure 3.3). As mentioned above, the Volga River is the primary input to the Caspian Sea, historically accounting for over 80% of freshwater discharge (Dumont 1995, p. 674) and 75% of sturgeons harvested from the Caspian Sea (Ruban and Khodorevskaya 2011, p. 202).

The Volgograd Dam destroyed access to 60–80% of the Volga's Russian sturgeon spawning grounds and 40–60% of those for stellate sturgeon; these now lie upstream of the dam (Fig. 3.3; Vlasenko 1982 cited in Ruban et al. 2019, p. 389; Ruban and Khodorevskaya 2011, pp. 199–200; Fashchevsky 2004, p. 195). Prior to the dam's construction, winter migrants spawned around Saratov, Russia and at points upstream (Ruban and Khodorevskaya 2011, p. 203). Now, they can only overwinter and spawn in the lower river adjacent to the dam. In the decades following the Volgograd's completion, these areas became overcrowded, as fish that once migrated farther upstream were forced to stop here (Slivka and Pavlov 1982 cited in Ruban and Khodorevskaya 2011, p. 203). Up to 70% percent of eggs laid in these spawning grounds did not hatch (Khoroshko 1972 and Novikova 1989 cited in Ruban and Khodorevskaya 2011, p. 203), possibly due to oxygen depletion by the densely aggregated fish. Sturgeon that overwinter in the Volga are more affected by the dam than are spring migrants because of the longer time spent near the dam (Ruban and Khodorevskaya 2011, p. 203).

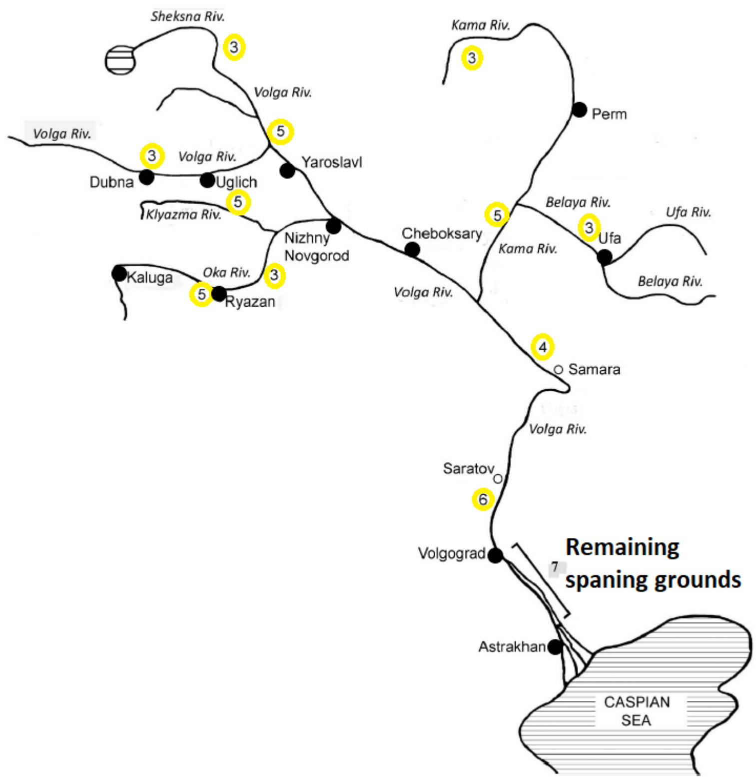


Figure 3.3—Dams (black circles) and sturgeon spawning grounds (yellow) in the Volga River and its main tributaries. Spawning grounds are those formerly used by Russian (3 and 4, winter and spring migrants, respectively) and stellate (5 and 6, winter and spring migrants, respectively) prior to dam construction. Figure edited and reproduced from Ruban et al. 2019 (Fig. 1).

In the Volga's remaining spawning grounds downstream of the dam, the annual sturgeon reproductive output now depends heavily on the volume and timing of water released from the upstream reservoir. In the first 40 years of dam operation, only 13 years saw the downstream spawning grounds flooded. In relatively dry years, sturgeon numbers recruited into the fishery can be six-to-seven times lower than in relatively wet years, although productivity is greatly depleted in all years compared to before dam construction (Khodorevskaya & Kalmykov 2014, p. 578). The spring peak water levels, which used to follow snowmelt, are now compressed into a shorter period (Fashchevsky 2004, p. 192). This means juvenile sturgeon are forced to migrate away from shallow spawning grounds earlier than they naturally would and that those surviving, arrive in the Caspian Sea at smaller size (Khodorevskaya et al. 2009 cited in Ruban et al. 2019, p. 389), likely more susceptible to predation and other threats. A lower-volume spring flood also reduces the initial size of spawning grounds, decreasing egg and larval survival (Ruban et al. 2019, p. 389).

While spring floods are limited below the Volgograd, high-volume winter releases from the reservoir compound the impacts of the artificial hydrological regime, too. Up to 30% of Russian sturgeon that overwinter below the dam fail to spawn after exhausting their energy reserves fighting the high velocity of dam outflows (Altufiev et al. 1984 cited in Ruban et al. 2019, p. 389).

Elsewhere, the results of large dam construction have been similarly devastating for Ponto-Caspian sturgeon. The Kakhov Dam was constructed on the Dnieper River in Ukraine in the early 1950s; immediately following its completion, the catch of migratory fish including beluga, Russian, and stellate sturgeon, and herring (Clupeida) fell by 80% (Fashchevsky 2004, p. 195). On the Dniester, the Dubossary reservoir, behind the dam of the same name, accumulated DDT and other pollutants (Fashchevsky 2004, p. 187). In the Caspian basin, several dams on the Terek River in Georgia and Russia block sturgeon passage (Askhabova et al. 2019, p. 557; Askhabova et al. 2018, p. 213).

The Danube River, responsible for over 50% of discharge to the Black Sea, is another representative case of the extent and impacts of damming in the Ponto-Caspian region. No fewer than 31 dams cross the Danube (Friedrich et al. 2019, p. 1061; Bacalbaşa-Dobrovici 1997, p. 201). The Iron Gates Dams built in 1970 and 1984 (Bacalbaşa-Dobrovici 1997, p. 201) created an isolated population of Russian sturgeon in the lower Danube (Billard and Lecointre 2001, p. 373), cutting off any previous genetic exchange the fish had with the remainder of the species. Russian sturgeon fishery landings declined by 90% in 1985, the year after the second of two Iron Gates Dams went into place (Gessner et al. 2010a, not paginated).

Since the mid-1980s, 85% of floodplains in the lower Danube—home to sturgeon spawning grounds and juvenile habitats—have been diked (Botzan 1984 cited in Bacalbaşa-Dobrovici 1997, p. 203). This increases water depths and flow rates, causing both migrating and recently hatched sturgeon to struggle, and reduces the abundance of sturgeon prey in these areas (WSCS and WWF 2018, p. 49).

To date, fish passage structures built or retrofitted into dams to facilitate fish movement past the barrier have generally been unsuccessful for large, slow-moving sturgeon trying to move through fast-flowing spillways (Fashchevsky 2004, p. 185; Billard and Lecointre 2001, p. 380). Such structures require low-flow resting pools and wide berths, if they are to aid sturgeon migration (Cai et al. 2013, p. 153).

Environmental concerns may be beginning to turn the tide of river management away from construction of new dams, at least in some parts of the Ponto-Caspian region. Recently, a Slovak Republic court forbid the licensing of a small hydropower plant on the already heavily dammed Hron River, a Danube tributary, because the environmental harm it would do was judged not in the public interest (WWF 2020a, not paginated). On the Dniester River in Ukraine, plans for six dams were shelved (WWF 2020a, not paginated). While beneficial to avoid further harm, halting new construction will have no restorative effects on sturgeon habitats, and dams are still being built in other regions (e.g., Iran, as described in Chapter 5, Scenario 1; Tehran Times 2020, not paginated).

Dams are far from the only water control structures engineered into Ponto-Caspian rivers, and all of irrigation and pumping stations, dredging, watercourse straightening, and water transfers between waterbodies affect sturgeon. Hundreds of manmade structures can exist on a single river (e.g., 812 on the Volga, 650 on the Dnieper, 79 on the Kura, and 91 on the Ural as of 2003; Fashchevsky 2004, pp. 183–184). Where rivers are straightened and deepened, shallow, low-velocity spawning habitats are often lost (WSCS and WWF 2018, p. 49). Flood control structures prevent water from entering the natural floodplain, greatly reducing the availability of invertebrate prey for sturgeon (WSCS and WWF 2018, p. 49).

Massive withdrawals for irrigation or drinking water can dry out or alter the timing of flooding on spawning grounds; for instance, 40–60% of the Ural's discharge was diverted in the early 2000s, although this river is actually better-off than most in the region because the lower 1800 km has not been dammed (Fig. 3.2; Lagutov and Lagutov 2008, p. 197; Fashchevsky 2004, pp. 194–196). Still, recent news reports indicate that water levels have continued to drop in the Ural, due to intensive water use for irrigation, industry, and drinking water (Trotsenko and Melnikova 2019, not paginated).

Water withdrawals from the inlets to the Aral Sea have had particularly devastating impacts. Beginning in the 1960s, diversion of water from the Syr-Darya and Amu Darya Rivers, especially in what is now Kazakhstan and Uzbekistan, greatly limited the volume of water entering the Aral Sea (Micklin 2007, entire). Whereas the Aral was the world's fourth largest inland waterbody in 1960, it shrank from over 67,000 km^2 to just over 14,000 km^2 (nearly an 80% decline) by 2006; moreover, this reduced extent was split among now-disjunct water bodies, with further declines continuing since then (Micklin 2007, p. 53). For at least 13 years (1974–1986), the Syr-Darya dried up before reaching the Aral Sea, and the same was true of the Amu-Darya for five years in the 1980s (Micklin 2007, p. 51).

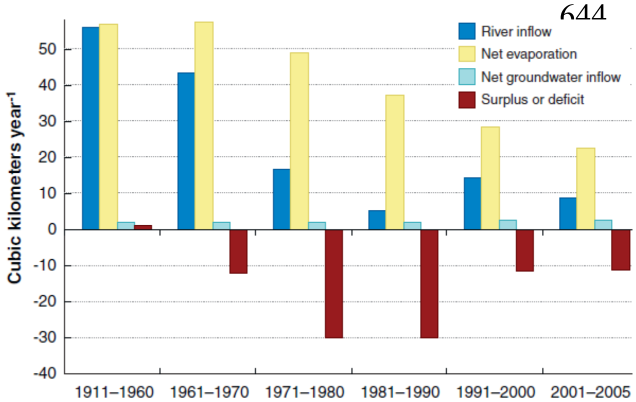


Figure 3.4—Aral Sea water balance, 1911–2005. The vast decline in river inflow from the Syr-Darya and Amu-Darya Rivers created extreme deficits in sea volume. Reproduced from Micklin 2007, p. 49 and references therein.

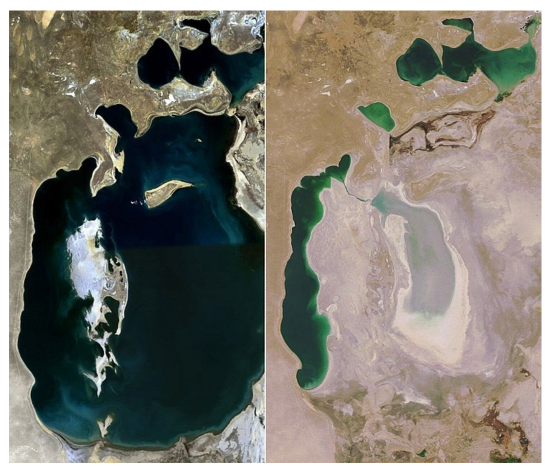


Figure 3.5—The Aral Sea as seen from overhead satellites in 1989 (left) and 2014 (right). From the bottom left to the top right of the image, the straight-line distance is approximately 400 km. Image in the public domain, created by NASA.

Regional governments value the economic benefits of the massive (if inefficient) irrigation provided by the water withdrawals, making extensive restoration unlikely, despite some limited progress from international donor-funded programs (Micklin 2007, pp. 60–61). Moreover, dams in both the Syr-Darya (just 20 km from its mouth) and the Amu-Darya block the migration path to most former spawning sites (Ermakhanov et al. 2012, p. 6; Zholdasova 1997, p. 374).

Canals built for shipping access connect previously separate waterways, shifting the composition of ecological communities sturgeon are a part of. In the case of the Volga-Don navigational canal, this connection aided the spread of an invasive species, the warty comb jelly *Mnemiopsis leidyi*, with grave environmental impact (see *Invasive species* below; Ivanov et al. 2000, p. 255). Ship noise and collisions in canals and elsewhere can also be a detriment to sturgeon migration, spawning, and other behavior (WSCS and WWF 2018, p. 49; He et al. 2017, p. 9).

Overfishing

History of Caspian Sea sturgeon fisheries

Long before dams proliferated in the Caspian Sea basin, commercial fisheries were the primary threat to the Ponto-Caspian sturgeon (Khodorevskaya and Kalmykov 2014, p. 577; Ruban and Khodorevskaya 2011, p. 199). Most sturgeon fishing is driven by the now-international demand for caviar; in the late 1990s and early 2000s, global demand amounted to 500 metric tons per year (Gessner et al. 2002, p. 665). Assuming 10% of fish biomass is roe (a generous estimate; Babushkin and Borzenko 1951 cited in Ruban and Khodorevskaya 2011, p. 199) and that sturgeon average around 20 kg body mass (similar to a recent estimate for wild-caught fish in the southern Caspian Sea; Tavakoli et al. 2018, p. 379) this would require well over 2 million fish annually. Today, overfishing and dams are the major threats to the region's sturgeon, and among all regions home to sturgeon worldwide, overfishing is considered worst in the Ponto-Caspian (Reinartz and Slavcheva 2016, p. 16).

Some historical fisheries data lump all local sturgeon species together. These combined data include the four species assessed here, plus the Caspian's other sturgeon species—beluga and sterlet. However, Russian sturgeon—sometimes combined with Persian sturgeon due to taxonomic uncertainty—has been the most abundant species in Caspian basin catches (around 50% of the fishery in most years since at least 1930, primarily in Russian waters; Ruban et al. 2011 entire; Ruban and Khodorevskaya 2011, pp. 200–202), with stellate sturgeon the next most common (mostly from Kazakh territory; Ruban and Khodorevskaya 2011, pp. 200–203). Ship sturgeon has long accounted for minimal catch volume compared to these other species.

In the 1600s, the Volga River sturgeon catch alone amounted to 50,000 metric tons of fish per year (likely on the order of a million fish annually), and as much as 37,000 metric tons were caught annually in the 1800s (Korobochkina 1964 cited in Khodorevskaya and Kalmykov 2014, p. 577; Ruban and Khodorevskaya 2011, p. 199). Between 35,000 and 39,000 metric tons of sturgeon were still caught each year in the Caspian Sea from 1901–1903, but overfishing led to a decline in sturgeon abundance and catch by 1914, with less than 30,000 metric tons caught (Khodorevskaya and Kalmykov 2014, p. 577; Korobochkina 1964 cited in Ruban and Khodorevskaya 2011, p. 199).

Although a reduction in fishing pressure during World War I allowed some stocks to rebound, by the late 1930s, the average size of Russian sturgeon caught had fallen by 50% from the period 1928–1930 (Ruban and Khodorevskaya 2011, p. 199). Long-term declines in the size of captured fish are a common indicator of over-exploited fisheries (Shackell et al. 2010, p. 1357; McClenachan 2009a pp. 636-643; McClenachan 2009b, pp 175-181), including for at-risk sturgeon from other regions (Koshelev et al. 2014, pp. 1129-1130).

Smaller females lay fewer eggs, reducing population resiliency after declines (Koshelev et al. 2014, pp. 1129-1130). In the Caspian basin, not only were remaining females smaller, the percent of their body mass that was eggs declined. Whereas this was 8.3% for 1926–1930, roe yield fell to 4.0% of fishery biomass for 1931–1935, and 2.6% between 1936 and 1940 (Babushkin and Borzenko 1951 cited in Ruban and Khodorevskaya 2011, p. 199). This means a greater number of fish were required to satisfy demand for wild-caught sturgeon and caviar, and that the ability of wild populations to withstand harvest was likely reduced.

Quotas and minimum fish size limits imposed on southern and central Caspian Sea sturgeon harvesting in 1938 combined with a strong downturn in fishing during World War II (Figs. 3.6 & 3.7) to allow limited recovery of sturgeon stocks (Ruban and Khodorevskaya 2011, p. 199). From the end of the 1940s, annual Caspian catch volumes (primarily by Russia's fishery) oscillated but generally increased for around 40 years to a peak of about 30,000 metric tons. (Figs. 3.6 & 3.7).

Starting in 1962, a near-complete ban on sturgeon fishing in the Caspian Sea was put in place (Ruban and Khodorevskaya 2011, p. 199). At the time, the ban's motivation may have been less so conservation and more because fishing was more easily regulated in the regions' rivers and deltas than on the open sea (Korobochkina 1964 cited in Ruban and Khodorevskaya 2011, p. 199). Still, some believe the ban was moderately effective for maintaining Russian, Persian, and stellate sturgeon stocks (Ruban and Khodorevskaya 2011, p. 199); by 1977, total sturgeon landings had recovered to the same levels as they were at in 1914–1915 (around 30,000 metric tons; Fig. 3.6 and 3.7). However, others indicate that the increased catch was not due to effective protection of the fish, but rather to increased efficiency of fishing operations (Lagutov and Lagutov 2008, p. 212). Only Iran continued to allow fishing in the Caspian Sea itself, and their fishery accounted for just 5–10% of landings 15 years after the ban began (Ivanov and Mazhnik 1997 cited in Ruban and Khodorevskaya 2011, p. 199).

From the time the ban on fishing in the Sea was instituted until the early 1980s, the Caspian fishery focused intensely on harvesting spring migrants moving into rivers (Ruban and Khodorevskaya 2011, 204). Despite the Volgograd Dam's impacts, the Volga River remained the primary fishery location, accounting for 90% of all Soviet sturgeon harvest, with 80 to 95% of Volga River spawners captured yearly (note that not all adults spawn each year, so this is not 80–95% of all adults; Ruban and Khodorevskaya 2011, p. 204). Much lesser volumes were caught in the Ural, Kura, and Terek Rivers (Ruban and Khodorevskaya 2011, p. 199), although these rivers were also home to smaller populations to begin with.

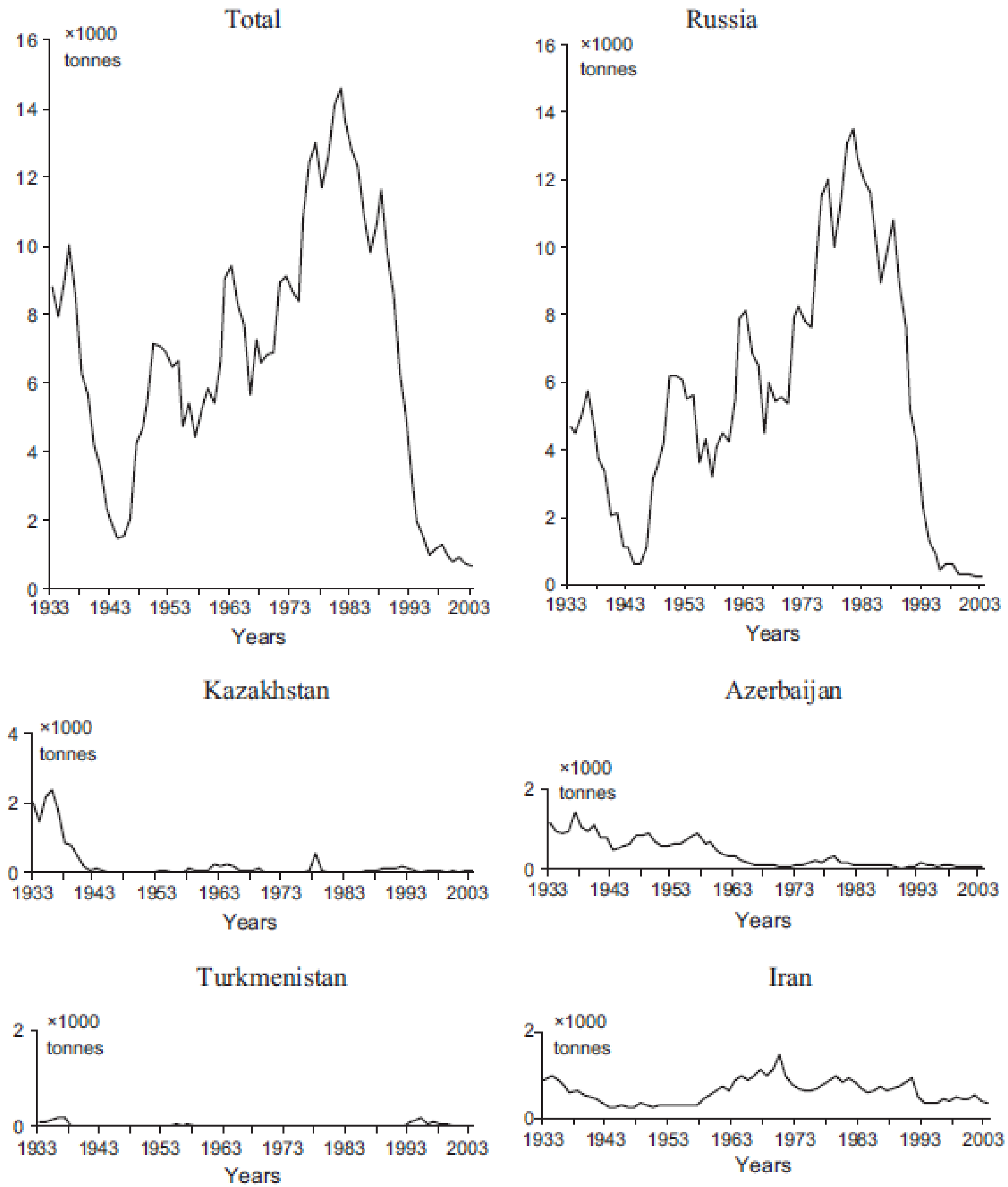


Figure 3.6—Russian plus Persian sturgeon harvest volumes (tonnes = metric tons) in the Caspian basin for 1933–2003 (Ruban and Khodorevskaya 2011, p. 202 and references therein).

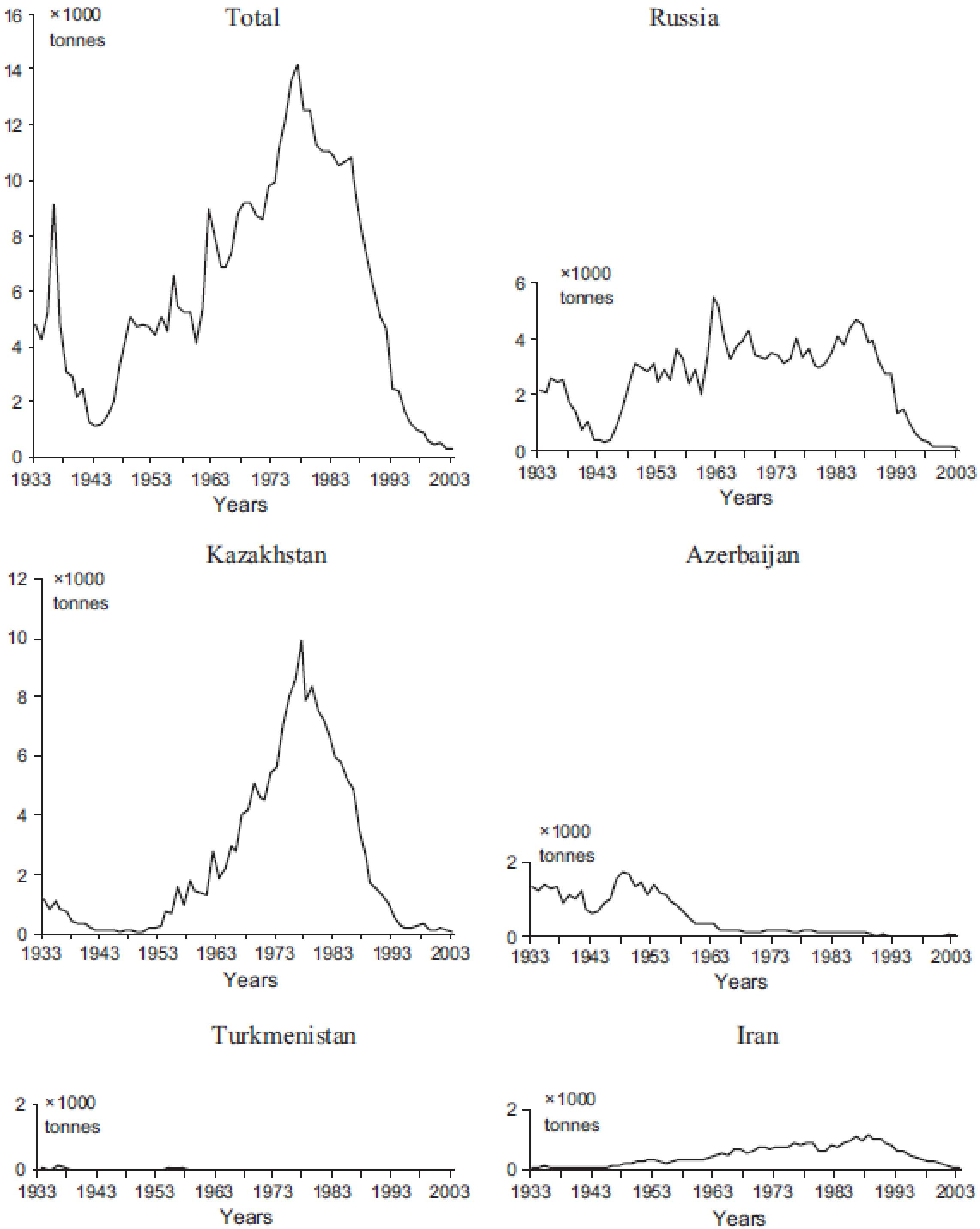


Figure 3.7—Stellate sturgeon harvest volumes (tonnes = metric tons) in the Caspian basin for 1933–2003 (Ruban and Khodorevskaya 2011, p. 203 and references therein).

In the late 1970s and early 1980s, sturgeon catches in the Caspian began to collapse. From their peak of around 30,000 metric tons in the mid-1970s, landings of Russian, Persian, and stellate sturgeon fell to 1,000–2000 metric tons per year by the early 2000s (Figs. 3.6 and 3.7). Although these catch declines appear to mirror those in the 1930s and 1940s from which sturgeon fisheries rebounded, the important distinction is that there was not an event analogous to World War II that accounts for the drop in fisheries landings.

In response to declining landings, in 1981, some types of fishing equipment were banned seasonally by Soviet authorities in portions of the Volga, including upstream of Astrakhan and on Glavnyi Bank (Ruban and Khodorevskaya 2011, 204). This led to a small pulse of sturgeon recruitment from 1981–1985, although fish did not use most available spawning grounds below the dam, (Khodorevskaya et al. 2009 cited in Ruban and Khodorevskaya 2011, 204) and the catch continued to free-fall thereafter.

Still-stricter regulations began in 1986 (Ruban and Khodorevskaya 2011, p. 204), but the Caspian basin catch was crashing fast (Figs. 3.6 & 3.7), due in large part, to increased poaching and overfishing in both the Sea itself and in rivers (Ruban and Khodorevskaya 2011, pp. 200–201, 204). There is some indication that the collapse of the Soviet Union, and the economic hardships that followed in the region, encouraged sturgeon poaching in the former Soviet territories (Ruban and Khodorevskaya 2011, p. 204). Indeed, by the late 1990s, the illegal catch of all sturgeon species was estimated to be six to 10 times the permitted fishery (CITES Animals Committee 2000, p. 47; Fashchevsky 2004, p. 186). Others suggest that the illicit catch may have been as much as 35 times greater than the total legal catch (Bobyrev et al. cited in Ruban et al. 2019, p. 389).

The fishery history in the Ural River parallels those of the Volga and of the Caspian as a whole. In the late 1800s and early 1900s, the Ural River fishery was comparably well-regulated by the Cossack military government; the populace relied so heavily on the river that its management was a major bureaucratic priority (Lagutov and Lagutov 2008, p. 209). Unauthorized sturgeon harvest was strictly forbidden (Lagutov and Lagutov 2008, p. 209). However, by the 1950s, the Ural was heavily overfished (Lagutov and Lagutov 2008, p. 209). The Ural fishery was dominated by stellate sturgeon (Lagutov & Lagutov 2008, p. 220) and Russia's 1962 ban on sturgeon fishing in the sea increased pressure on Ural River fish (Lagutov and Lagutov 2008, p. 212).

The Ural River sturgeon catch (all species) peaked in the late 1970s at about 10,000 metric tons, 30% of the Caspian harvest (Lagutov and Lagutov 2008, p. 213). Thereafter, the catch continuously declined to near-zero by the early 2000s (Lagutov and Lagutov 2008, p. 213). In the late 1990s, as the Soviet collapse encouraged increased poaching, up to 60% of spawning ship plus beluga sturgeon were caught in the Ural annually (Lagutov and Lagutov 2008, p. 219). In most years from 1993–2007, even ever-shrinking Kazakh quotas for sturgeon harvest in the Ural basin were not met because there were too few fish remaining (Lagutov and Lagutov 2008, p. 213).

The Terek, Kura, and Sefid-Rud Rivers' fishery volumes never approached those of the Volga and Ural (Lagutov and Lagutov 2008, p. 198). They accounted for approximately 1% of all sturgeon harvest in the Caspian basin (Lagutov and Lagutov 2008, p. 198), but have similarly been fished to near-extirpation (Lagutov & Lagutov 2008, p. 223). Prior to the mid-1960s, 1–2 metric tons of Russian sturgeon were harvested from the Kura River annually, but these landings declined to less than half a ton in the 1970s and to near-zero thereafter (Lagutov & Lagutov 2008, p. 222). Four-to-five tons of ship sturgeon were caught per year in the Kura River in the 1980s (Lagutov & Lagutov 2008, p. 227)

Overall, Caspian Sea sturgeon landings declined by more than 95% from their 1977 peak to 2003, when only about 1,000–2,000 metric tons were captured in the Caspian Basin (Ruban and Khodorevskaya 2011, p. 200). This is 2% of the volume caught in just the Volga River in the 1600s and just over 3% of that caught little over a century ago (Khodorevskaya and Kalmykov 2014, p. 577; Korobochkina 1964 cited in Ruban and Khodorevskaya 2011, p. 199; Ruban and Khodorevskaya 2011, p. 199). Declines in commercial catch volume are widely believed to reflect population size in sturgeon (Suciu and Qiwei 2010, not paginated). In 2005, Russia instituted a complete ban, including in rivers, of commercial harvest of Russian (including Persian; per Ruban et al. 2011, entire) and stellate sturgeon (Ruban et al. 2019, p. 389).

History of Aral Sea sturgeon fisheries

From 1928–1935, 3000–4000 metric tons of ship sturgeon were harvested from the Aral Sea basin annually (Zholdasova 1997, p. 379). Following decimation of the region's ship sturgeon stock by the introduced parasite *Nitzschia* (see *Disease and predation* below), the fishery was closed from 1940 until at least 1960, when it resumed at very low levels (0.7–9 metric tons per year; Zholdasova 1997, p. 379). From the 1970s on, though, intensive illegal fishing caused the remaining population to decline, and by 1984, there was no fishery (Zholdasova et al. 1997, pp. 376–379). Thereafter, ship sturgeon were hardly seen again in the Amu-Darya or Syr-Darya (Zholdasova et al. 1997, pp. 376–379).

History of Black and Azov Sea sturgeon fisheries

As in the Caspian Basin's Volga River, medieval era sturgeon catch records indicate prodigious volumes of the fish were caught in the Black Sea basin several centuries ago. Remarkably, in 1548, the Vienna, Austria fish market once sold 50,000 metric tons of sturgeon (including sterlet, beluga, and European sturgeon) from the Danube River in just a few days (Krisch 1900 cited in Friedrich et al. 2019 p. 1060). In the 1600s, 1000–2000 sturgeon were brought to market in a single Romanian town, Chilia, each day (Bacalbaşa-Dobrovici 1997, p. 202). However, large sturgeon were already rare in the middle and upstream portions of the Danube by the 1800s (Heckel and Kner 1858 and Schmall & Friedrich 2014 cited in Friedrich 2019, p. 1060) with population declines due to overfishing underway (Bacalbaşa-Dobrovici 1997, p. 202).

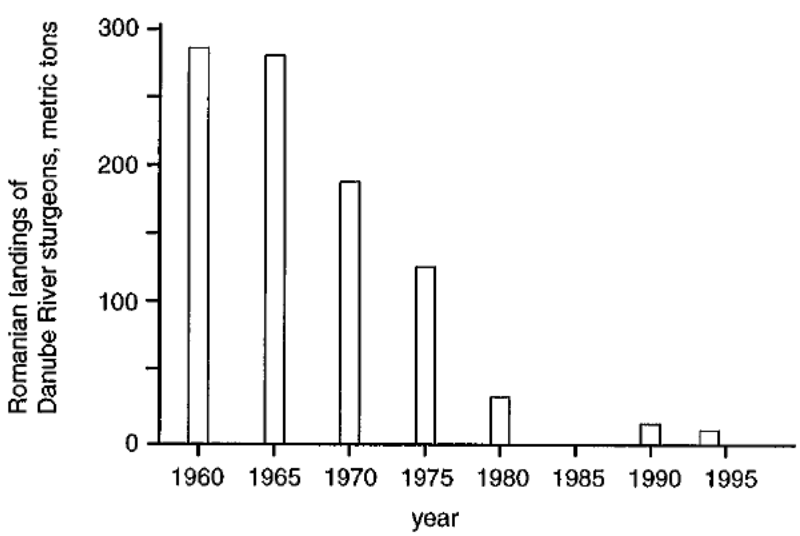


Figure 3.8—Romanian catch of sturgeon in the Danube River, 1960 – 1994. Reproduced from Bacalbasa-Dobrovici 1997, p. 203.

Sturgeon fishing on Romania's portion of the lower Danube was tightly controlled beginning with Communist rule in 1947, but even so, the catch declined precipitously during the 2nd half of the 20th century. Whereas nearly 300 metric tons of sturgeon (all species) were caught in 1960 and 1965, this fell to less than 25 metric tons by 1990 (Fig. 3.8). Similar catastrophic declines in catch volume occurred on the Ukranian Danube, with almost no fish caught by 2000 (Reinartz et al. 2020a, p. 8).

Fishing effort did not wane on the Romanian Danube, despite much-decreased catch. By 2000, over 80 fishing sites were established along many hundreds of km of the Romanian Danube, where previously all fishing had been focused on one regulated area (Suciu 2008, p. 11). In 2001, 1200 individuals were licensed as sturgeon fishermen in Romania (Suciu 2008, p. 16). However, by 2006, no commercial fishing of sturgeon was permitted in the country (Suciu 2008, p. 17). Then, the only legal harvest consisted of about 200 fish per year for use as spawners in small farming operations (Suciu 2008, p. 17). The abundances of Russian, ship, and stellate sturgeon have all declined greatly in the lower Danube (Bacalbaşa-Dobrovici 1997, p. 203).

Also, trawl nets in the Danube destroyed river bottom habitats (Bacalbaşa-Dobrovici 1997, pp. 205–206). Compared to the 1930s, by the 1980s, over two-thirds of river-bottom species and about 60% of their abundance had been lost; many of these are sturgeon prey items (Bacalbaşa-Dobrovici 1997, pp. 205–206). Historically, fishing was done with rods. But the introduction of large nets was a game-changer; one fisherman called them "endless fences in the Black Sea" (Luca et al. 2020, not paginated).

In the Kizilirmak and other Turkish Rivers, overfishing coupled with dams led to a collapse of the fishery in the 1970s (Memiş 2014, p. 1552). Whereas legal Turkish sturgeon landings (all sturgeon species) were as high as 300 metric tons in the early 1960s, this volume dropped to just 4 metric tons in 1979 (Memiş 2014, p. 1555). Despite a ban since 1980 on catching Ponto-Caspian sturgeon above 140 cm, illegal fishing continued to reap up to 15 metric tons of all sturgeon species annually in the 1990s (Memiş 2014, p. 1555). Illegal fishing is said to have slowed, then ceased in 2005 (Memiş 2014, p. 1555), although it is not clear whether this is because of better enforcement or the exhaustion of the sturgeon population. By the late 1990s, as in the Caspian Sea, the illegal catch of all sturgeon species in the Black and Azov Sea basins was estimated to be six to 10 times greater than the legal fishery (CITES Animals Committee 2000, p. 47; Fashchevsky 2004, p. 186).

Few historical sturgeon data specific to the Dnieper, Southern Bug, Dniester, and Rioni rivers are available. However, the Ponto-Caspian sturgeon populations are much reduced in these rivers, where they also were not as abundant to begin with (Vecsei 2001, p. 362; Fauna and Flora International 2019a, entire).

CITES regulation

Since 1998, all sturgeon species have been included in Appendix II of CITES, except two species that were previously included in Appendix I (Ruban and Qiwei 2010, not paginated; Wang and Chang 2006, p. 48). National laws implementing CITES regulate international trade in listed species through a system of permits and certificates that must be presented upon import and export. Following the 1998 listing, CITES Parties adopted a series of recommendations to improve regulation of the international sturgeon trade (Harris and Shirashi 2018, pp. 19–22). These include:

1. annual reporting of scientifically informed quotas for any legal wild-caught sturgeon from "shared stocks" of sturgeon, i.e., those that inhabit the waters of more than one country [CITES Resolution Conf. 12.7 (Rev. CoP17)];

2. a caviar labeling system with certain information that must be present on the labels of internationally sold caviar to verify its legal origin [CITES Resolution Conf. 12.7 (Rev. CoP17); 50 CFR § 23.71(b) and USFWS OLE March 13, 2008];
3. registration of caviar-production companies;
4. recommendation for countries to establish export quotas set at a non-detriment level by a national Scientific Authority (i.e., to ensure that the species is maintained throughout its range at a level consistent with its role in the ecosystems in which it occurs; CITES Resolution Conf. 14.7 (Rev. CoP15)];
5. an exemption from CITES regulation for personal (non-commercial) import/export of 125g or less of sturgeon caviar per trip (50 CFR 23.15; USFWS undated; CITES 2015, 2e).

For 2020, all quotas for the Ponto-Caspian species were zero or were not reported (United Nations Environment Programme 2020, not paginated). In addition, other than Iran, no country reported a quota greater than zero since at least 2011 for any of the four Ponto-Caspian sturgeon UNEP 2020, not paginated). Thus, it is not clear if any international trade in shared stocks of wild-sourced Ponto-Caspian sturgeon can be considered legal today (Harris and Shiraishi 2018, pp. 9–10).

CITES labeling requirements for international trade include documentation of caviar origin, species, date of packaging, and trade permissions, but these stipulations are often not met (WSCS and WWF 2018, p. 66; Harris and Shiraishi 2018, p. 9). Neither most range states of Ponto-Caspian sturgeons nor the U.S. (Harris and Shiraishi 2018, pp. 35, 50) require the recommended CITES-style labeling for domestic caviar sales (Harris and Shiraishi 2018, p. 11). This may enable fraudulent sale of mislabeled caviar or the sale of sturgeon products whose origin is undocumented or misstated as being derived from aquaculture (Harris and Shiraishi 2018, p. 48). Moreover, legitimate CITES-endorsed labels and containers are believed to be resold on the black market to aid transport of illegal caviar (van Uhm and Siegel 2016, p. 81)

Nonetheless, CITES recommendations, along with increased enforcement (including by the Service Office of Law Enforcement) may be improving the situation slightly. Whereas 23% of caviar items bought from New York retailers were mislabeled in 1995–1996 (pre-CITES listing), this rate dropped to 10% between 2006 and 2008 (Doukakis et al. 2012 pp. 3–4; Birstein et al. 1998, p. 771). Still, there were items for sale as beluga and stellate sturgeon that were identified through DNA sampling as Russian sturgeon, caviar sold as stellate sturgeon that was actually American paddlefish (*Polyodon spathula*), Russian sturgeon, or sterlet, and even northern pike (*Esox lucius*) eggs sold as “Caspian Sea Black Caviar” (Doukakis et al. 2012, p. 458).

Recent and current fishing pressure and the legal sturgeon and caviar trade

The legal international trade in Ponto-Caspian sturgeon is now dominated by sale of farmed Russian sturgeon caviar and meat, with wild-sourced caviar at near-zero levels of trade (Figs. 3.9–3.10). This mirrors global trends in legal trade of all sturgeon. Between 2000 and 2015, worldwide, approximately 1600 metric tons of caviar was legally traded internationally according to CITES import records, although this does not include domestic, illegal, unreported or intra-European Union trade (Harris and Shiraishi 2018, p. 8). The contribution of farmed products to this tally rose during this interval to a high of 95% in 2015 (Harris and Shiraishi 2018, p. 8); in contrast, nearly 100% had been wild-sourced in 2000 (CITES Trade database cited in Harris and Shiraishi 2018, p. 25).

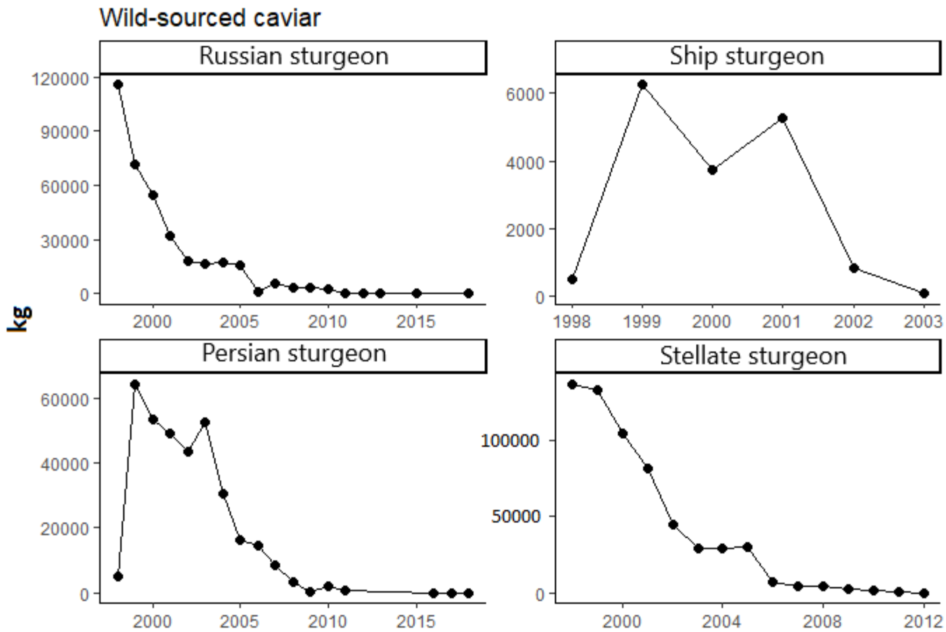


Figure 3.9—Volume of legal wild-sourced caviar traded globally from 1998–2018 for Russian, ship, Persian, and stellate sturgeon. Data are from the CITES Trade Database for source code "wild" and term codes "caviar" and "eggs." A small number of records reported without a volume or doing so in units that cannot be converted to weight were removed. No such trade was reported in the database beyond 2003 for ship sturgeon and 2012 for stellate sturgeon. Small inconsistencies between these data and the U.S.-specific CITES Annual Report data (e.g., small volumes of wild-sourced stellate sturgeon caviar traded to the U.S. in 2014; Fig. 3.12 and 3.13) are as supplied in the original databases.

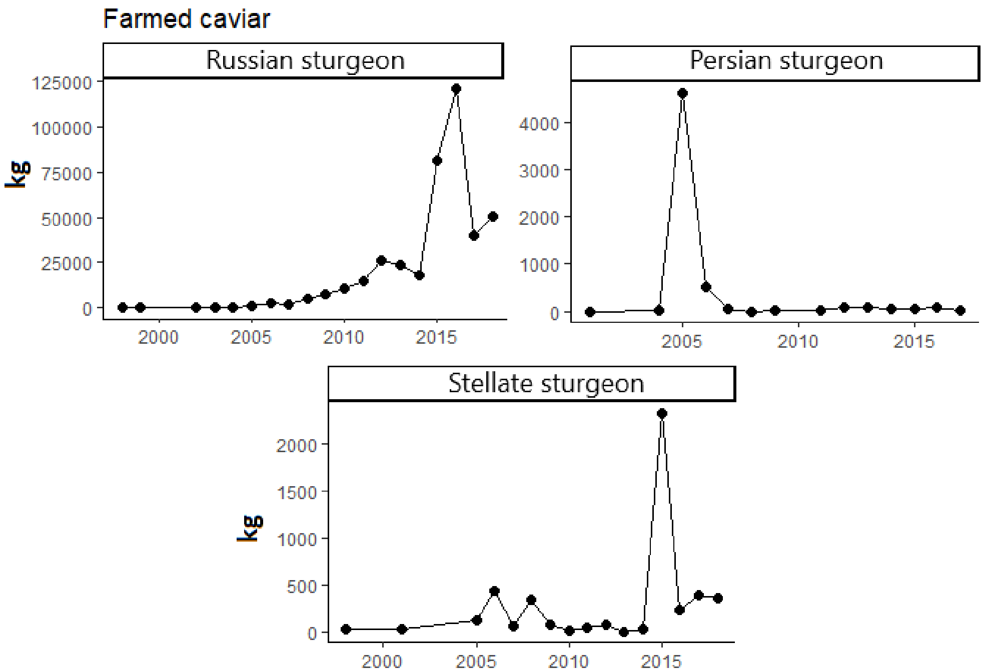


Figure 3.10—Volume of farmed caviar traded globally from 1998–2018 for Russian, Persian, and stellate sturgeon. There were no records of trade in farmed ship sturgeon caviar. Data are from the CITES Trade Database for source codes "farmed" and "ranched" and term codes "caviar" and "eggs." A small number of records not reporting volume or doing so in units that cannot be converted to weight were removed.

Over 50 metric tons of Russian sturgeon caviar trade was reported to CITES in 2018 (CITES Trade Database, 2020). No ship sturgeon and only 353 kg of stellate sturgeon and 14 g of Persian sturgeon caviar were reported that year. Nearly all reported trade in Ponto-Caspian sturgeon meat was also Russian sturgeon, with approximately 550 metric tons recorded (Fig. 3.11). Three metric tons of stellate sturgeon meat were traded internationally according to the CITES data, but no such trade in ship or Persian sturgeon meat was reported. Less than 10 kg of international trade in live eggs of each species was reported.

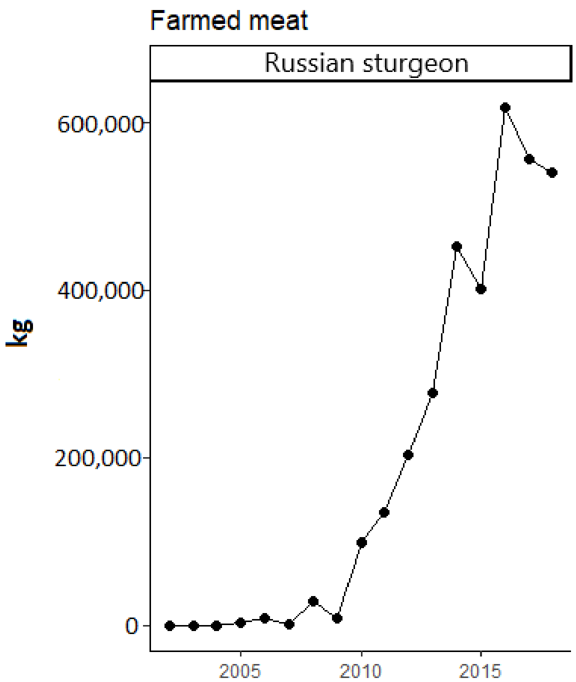


Figure 3.11—Volume of farmed Russian sturgeon meat traded globally from 1998–2018. Data are from the CITES Trade Database for source codes "farmed" and "ranched" and term codes "meat" and "bodies." A small number of records not reporting volume or doing so in units that cannot be converted to weight were removed. There were no records of trade in farmed meat for the other Ponto-Caspian sturgeon.

Russian sturgeon was also one of the top three species among all sturgeon by volume of wild-sourced caviar in international trade between 2010 and 2015 (Harris and Shiraishi 2018, p. 8) and was the most heavily traded species in terms of meat volume over the same period (659 metric tonnes; CITES Trade Database cited in Harris and Shiraishi 2018, p. 28). China, Italy, Moldova, Armenia, and Uruguay were the biggest consumers of sturgeon meat over this period (Harris and Shiraishi 2018, p. 28).

Farmed Russian sturgeon are exported in large numbers (250,000 annually) from Hungary (Gessner et al. 2010a, not paginated). Their caviar is used not only as food, but as an ingredient in cosmetics and pharmaceuticals, and their skin is used for leather. Russian sturgeon cartilage is used in medicines, and their intestines for sauces and in the production of gelatin (Gessner et al. 2010a, not paginated). Their swim bladder can be used to make glue (Gessner et al. 2010a, not paginated).

The U.S. has been the largest importer of sturgeon and sturgeon products since 1998 (Harris and Shiraishi 2018, p. 26; UNEP-WCMC 2012, p. 22). Between 2015 and 2018, the U.S. share of caviar imports (223,000 kg; all sturgeon species) was over 80% higher than that of the next-largest importing country, Denmark. Along with the U.S., the United Arab Emirates, Germany, France, and Japan were the biggest importers of caviar between 2010 and 2015.

As is true at the global scale, U.S. imports of Ponto-Caspian sturgeon products are dominated by Russian sturgeon in recent years (Fig. 3.12). Most of this is now captive-sourced caviar, although Russian sturgeon meat, live eggs, and extracts (likely for cosmetics) are also commonly traded to the U.S. (Fig. 3.13). Meat, live eggs, and extracts from other Ponto-Caspian taxa are imported to the U.S. in negligible quantities (CITES Annual Report database, 1998–2018). Fisheries in the Black and Caspian Sea basins and targeting non-sturgeon species also contribute to sturgeon endangerment through by-catch, although there are few hard data to quantify this threat (Reinartz et al. 2020a, p. 25; Tavakoli et al. 2018, p. 379).

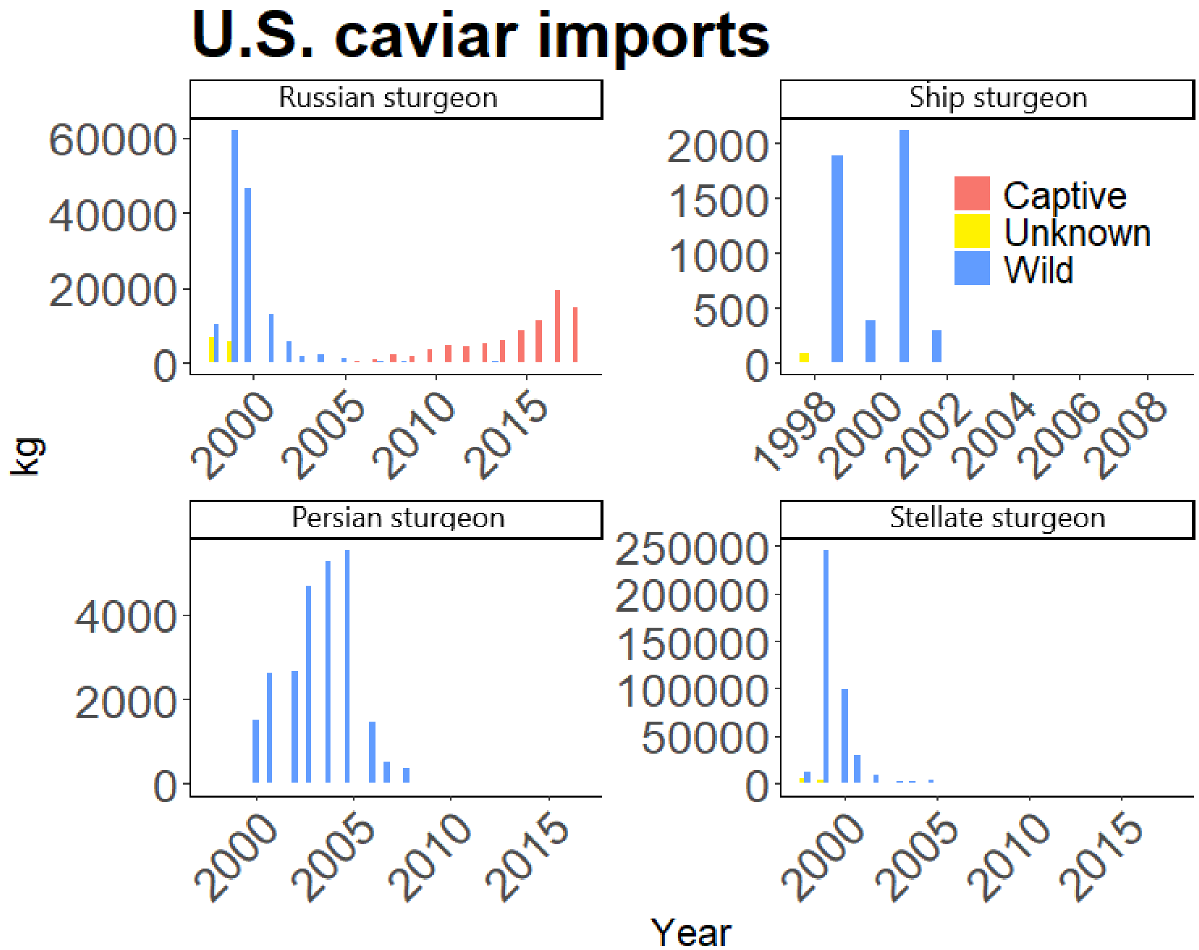


Figure 3.12—kg of caviar legally imported to the United States between 1998 and 2018 for each of the four Ponto-Caspian sturgeon. Data are from the CITES Annual Report database, provided by the Service's International Affairs program. Wild-sourced caviar (blue bars) includes CITES source codes W and R for wild and ranched fish, captive-sourced caviar (red bars) includes codes C, D, and F (all from captive or farmed-hatched fish), and yellow bars are caviar of unknown origin (codes I, O, P, and U). A small number of records (< 1%) missing volumes or reporting in units that could not be converted to mass were removed before plotting.

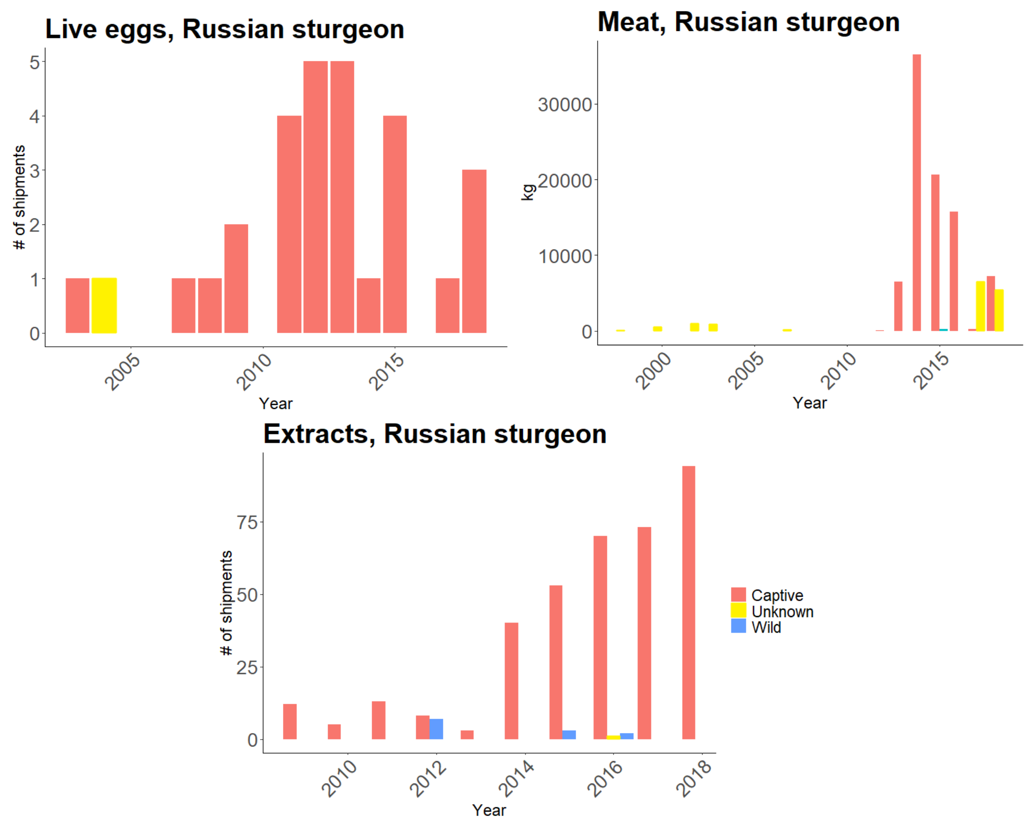


Figure 3.13—Shipments of Russian sturgeon extracts, live eggs, and meat (kg) imported to the United States between 1998 and 2018. Data are from the CITES Annual Report database, provided by the Service's International Affairs program. Wild-sourced products (blue bars) include CITES source codes W and R for wild and ranched fish, captive-sourced products (red bars) include codes C, D, and F (all from captive or farmed-hatched fish), and yellow bars are products of unknown origin (codes I, O, P, and U). A small number of records (< 1%) missing volumes or reporting in units that could not be converted to mass were removed before plotting.

In recent market surveys, Russian sturgeon was frequently available for sale online and in person in Germany, France, the U.S., and China, among other countries; stellate sturgeon (often marketed as "sevruga caviar") was also available, although less frequently (Harris and Shiraishi 2018, pp. 9 & 41–48). In many cases, the origin (geographic and whether farmed or wild) of caviar for sale online is not specified (Harris and Shiraishi 2018, pp. 41–45).

Although some consumers accept farmed caviar as equivalent to wild-sourced products (Harris and Shiraishi 2018, p. 39), people inherently prefer caviar from rarer species. This preference can help drive a continued market for illegal wild-sourced caviar and could drive species to extinction (Gault et al. 2008, pp. 202–205).

Recent illegal sturgeon and caviar trade

Although difficult to monitor (Harris and Shiraishi 2018, pp. 16–17), the illegal trade in sturgeon products is generally thought to remain robust, potentially accounting worldwide and across sturgeon species for 10 times the volume of caviar as in legal trade (Nelleman et al. 2014 cited in Harris and Shiraishi 2018, p. 14). In the Ponto-Caspian region, illegal harvest continues (Reinartz et al. 2020c, entire; WSCS and WWF 2018, p. 8; Reinartz and Slavcheva 2016, pp. 44–

49; Jahrl 2013, entire), and at least into the early 2010s, was much greater than any legal harvest in the Caspian basin (Ruban and Khodorevskaya 2011, 204).

Fisheries landings are likely under-recorded (Lagutov and Lagutov 2008, p. 239) and poaching is estimated to yield over 100 metric tons of sturgeon (all species) per year in the northern Caspian basin (Ermolin and Svolkinas 2018, p. 17). Organized crime and extensive corruption associated with sturgeon poaching on the Ural has even led in exceptional cases to militant violence against enforcement officers (Lagutov and Lagutov 2008, p. 239).

Seizures of illegally traded caviar continued in the Black Sea basin in recent years (Kecse-Nagy 2011, pp. 10–11 and Tables 6 & 7). Between 2014 and 2019, Danube Delta Police confiscated 640 kg of poached sturgeon and some Black Sea basin fishermen state that they have few alternatives for making money (Luca et al. 2020, not paginated). Among three lower Danube countries—Bulgaria, Romania, and Ukraine—a total of 175 sturgeon poaching incidents including Russian, stellate, and possibly ship sturgeon, were reported by law enforcement between 2016 and May 2020 (Reinartz et al. 2020b, p. 4).

Other investigations reveal continued illegal catch and trade of wild-caught sturgeon is widespread in the Black Sea basin. Despite bans on fishing for sturgeon in the Danube (Jahrl 2013, p. 6), illegal catch and sale continued as of 2020 in Bulgaria, Romania, Ukraine, and Serbia (Reinartz et al. 2020b, p. 2–4). Russian and Persian sturgeon (as well as beluga and Siberian sturgeon) were confirmed by DNA methods to be the source of some caviar for sale, although other putative sturgeon products were produced from other fish (Reinartz et al. 2020b, p. 2; Jahrl 2013, entire). Fishermen reported using relatively sophisticated methods including sonar and explicitly banned techniques such as hooked lines (Jahrl 2013, p. 3). However, there are no reliable quantitative studies of the illegal trade volume.

Concerningly, although commercial aquaculture operations are purported to reduce demand for wild-sourced caviar, some may worsen the effects of illegal fishing in Romania and Bulgaria. Some farms were believed to retain wild-caught broodstock that were intended to be released after spawning and may even have killed these fish to sell their caviar (Jahrl 2013, pp. 12, 15–16, 34 – 35). There is also speculation that some companies producing and selling farmed caviar may participate in laundering of wild-sourced illegal caviar into the legal market in Romania, Bulgaria, and the Caspian basin, too (Jahrl 2013, p. 12). We do not know whether these practices are exceptional or relatively common.

Between 2000 and 2016, U.S. authorities seized 1590 metric tons of illegally traded caviar Russian sturgeon was a common species among those traded illegally to the U.S. (Harris and Shiraishi 2018, p. 8). In 2013 and 2014, Service investigations of U.S. caviar trade revealed that each year, most major importers on the East coast were illegally importing millions of dollars-worth of caviar (Wyler and Sheikh 2013, p. 10; Zabyelina, 2014 cited in Harris and Shiraishi 2018, p. 48). In the European Union, 302 metric tons of illegal caviar were confiscated between 2000 and 2016 (Harris and Shiraishi 2018, p. 8).

In 2018 in the Astrakhan region of Russia, which borders the Caspian Sea, some vendors indicated that wild-sourced caviar was no longer available because of sturgeon declines (Harris and Shiraishi 2018, p. 39). However, others said illegal trade in such caviar was easier to come by in the spawning season (Harris and Shiraishi 2018, p. 40), and both Azerbaijan and Armenia are suspected of being sources for illegal Caspian Sea caviar traded to Russia and the EU (Fauna and Flora International 2019b, p. 8). In 2011 and 2012, some shops in Bulgaria and Romania reported much-reduced demand for caviar, so much so that it was rarely stocked (Jahrl 2013, p. 22).

In Russia's Republic of Dagestan and along the Volga River, interviews with three dozen fishermen catching sturgeon illegally revealed that an average fishing trip between 2013 and 2016 would yield around 250 kg of sturgeon by gillnet or 425 kg by bottom-line (Ermolin and Svolkinas 2018, p. 12) and there were around 400 boats fishing illegally in the region (Ermolin and Svolkinas 2018, p. 17). However, interviewees reported that in the early 2000s, it was regularly possible to catch 1000–2000 kg. Still, fishermen in some places can earn the equivalent of full year's income from sale of a single large fish (Harris and Shiraishi 2018, p. 40) and reports only a decade ago put the volume of illegal caviar in the Moscow market at 250 metric tons annually, 25–30 times that which arrived legally from caviar farms (Garrels 2010, not paginated).

The Dagestan and Kalmykia coasts along the northwest Caspian and the Volga River are poaching hotspots in Russia (Harris and Shiraishi 2018, p. 33) and according to some experts, most fish poached from the Caspian basin today are sold domestically in Russia, not on the international market (Gessner and Ludwig 2020, pers. comm.). However, known trade routes run from the Caspian Sea overland to Moscow, or via Belarus, Poland, Georgia, and/or Turkey into the EU (van Uhm and Siegel 2016, p. 79) and Russian businesses are believed to be involved in the sale of illegal caviar in Europe and North America (Harris and Shiraishi 2018, p. 33).

In the eastern Black Sea region (Georgia, northeast Turkey, and far southwestern Russia), vendors can fetch prices 30% higher for wild compared to farmed fish (Fauna and Flora International 2019a, pp. 2–3). This drives a continuing, robust, and illegal harvest in the region, with several dozen boats participating in the Georgian coastal zone and using illegal fishing techniques (e.g., electrofishing with car batteries; Fauna and Flora International 2019a, p. 3). In the Rioni River, poaching is especially prevalent at its mouth and around the town of Samtredia, about 70 km upstream (Fauna and Flora International 2019b, p. 4). Fishermen in the region are generally not relying on illegal sturgeon trade for their livelihood, but rather are supplementing their income this way (Fauna and Flora International 2019a, p. 3). Moreover, there is little evidence of organized crime being involved in sturgeon harvest in this region, possibly because the fish are too rare to support such an enterprise (Fauna and Flora International 2019a, p. 3).

There is only weak law enforcement capacity in the eastern Black Sea (Fauna and Flora International 2019a, p. 4). Non-governmental volunteers supplement official capabilities in this region but have not stopped the trade (Fauna and Flora International 2019a, pp. 2–4). Fish are likely smuggled from Georgian waters to Turkey (Fauna and Flora International 2019a, p. 4). Over 50 Turkish and Georgian boats fishing for anchovy are also suspected of collecting Black Sea sturgeon as bycatch (unintended harvest caught in the process of fishing for other species; Fauna and Flora International 2019a, p. 7; Fauna and Flora International 2019b, p. 6).

Finally, where reports to CITES of caviar imported from a given country are higher than that country's reported exports, exporters may be skirting the established CITES regulations (Harris and Shiraishi 2018, p. 22). Data from several Ponto-Caspian range states (Iran, Azerbaijan, and Russia, among others) all had such discrepancies for some years between 2000 and 2010 (Harris and Shiraishi 2018, p. 23). Indeed, Iran, Russia, and Kazakhstan often did not report any caviar exports between 2006 and 2010, despite allowing sturgeon trade (Harris and Shiraishi 2018, p. 23).

National and multilateral fisheries legislation and enforcement

Across the 20-plus countries that comprise the ranges of Ponto-Caspian sturgeons, there is a patchwork of legal efforts aimed at regulating the harvest, farming, and trade of the species. We do not aim to give a comprehensive overview; the rules are many (WSCS and WWF 2018, pp. 63–75; Mammadov et al. 2014, Section 2.1) but have rarely been effective for protecting and recovering diminished sturgeon populations (WSCS and WWF 2018, p. 6). Economic interests, corruption, the large profits available from illegal trade, a failure to act before sturgeon stocks crashed, unnecessary complexity, the largely voluntary nature of agreements, and a lack of public awareness all conspire to make most national and multilateral legislation ineffective (WSCS and WWF 2018, p. 6; Mammadov et al. 2014, Section 2.1; Lagutov and Lagutov 2008, p. 239). We provide some examples of relevant legislation but also note that few countries have outright banned the catch of sturgeon (Suciu and Qiwei 2010, not paginated).

As of 2020, Russia is in the process of updating its Red Data Book to include the Ponto-Caspian sturgeon (Gessner, Congiu, and Ludwig 2020, pers. comm.; Harris and Shiraishi 2018, p. 34). If completed, including the present species would ban their commercial sale and habitat destruction. The Russian criminal code makes harvest, trade, and possession of listed species punishable by up to three years in prison (Harris and Shiraishi 2018, p. 34).

Regardless, commercial fishing for sturgeon in the Caspian Sea (but not its rivers) is already banned by Russia since 2007 (Harris and Shiraishi 2018, p. 34) and, more recently, by all five Caspian states (Russia, Iran, Turkmenistan, Azerbaijan, and Kazakhstan; President of Russia 2018, not paginated).

As of 2020, all Danube River nations had banned sturgeon fishing in the river, although Bulgaria and Romania were due to decide on renewal of their bans in early 2021 (Reinartz et al. 2020d, p. 1). Broader regional agreements with relevance for sturgeon conservation (but again, that have not measurably improved sturgeon status) include the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), the Convention on the Protection of the Black Sea against Pollution (Bucharest Convention), and the European Directive on the Protection of Flora, Fauna, and Habitats (WSCS and WWF 2018, pp. 66–72). Most recently, the WSCS and WWF (50 partner countries and the EU) agreed to the Pan-European Action Plan for Sturgeons, which lays out a comprehensive roadmap for recovery of the continent's sturgeon; however, the plan is a non-binding roadmap (WSCS and WWF 2018, entire).

Invasive species

In 1982, the western Atlantic ctenopohore *Mnemiopsis leadyi* (a comb jelly; hereafter "*Mnemiopsis*") was documented for the first time in the Black Sea (Pereladov 1983 cited in Ivanov et al. 2000, p. 255). The species, widespread and native in western hemisphere estuaries, has had vast impacts on Ponto-Caspian food webs, including on sturgeon by reducing prey abundance (Shiganova et al. 2019, entire; Kamakin and Khodorevskaya 2018, entire; Ivanov 2000, entire). *Mnemiopsis* was very likely introduced to the Black Sea in ship ballast water and then proliferated thanks to abundant nutrients and food resources, its hermaphroditic, self-fertilizing reproductive nature, tolerance of widely varying salinities, and the absence of natural predators (Ivanov et al. 2000, p. 255).

By 1988, the biomass of *Mnemiopsis* in the Black Sea ballooned to 1.1 billion metric tons, greater than all the fish caught worldwide that year (Sorokin et al. 2001 cited in Ivanov et al.

2000, p. 255). It spread through the Black Sea where it flourished and was found at densities as high as 21,000 individuals per m^2 (Mirsoyan et al. 2006 cited in Shiganova and Shirshov 2011, p. 35).

Mnemiopsis feeds on zooplankton, floating fish eggs (not those of sturgeon, which adhere to the benthos), and fish larva (Tzikhon-Lukanina et al. 1993 cited in Ivanov et al. 2000, p. 256). In a single day, *Mnemiopsis* individuals may ingest over 10 times their own body mass, although much of this is then regurgitated; this behavior increases the species' destructive impacts where it is introduced (Kremer 1979 cited in Ivanov et al. 2000, p. 256).

Mnemiopsis blooms in both the Black and Azov Seas caused zooplankton abundance to decrease dramatically and pelagic fish stocks to crash because of both direct predation and the loss of their zooplankton prey (Shiganova and Bulgakova 2000 cited in Ivanov et al. 2000, p. 256). These pelagic fish declines included mackerel, anchovy, and kilka, several species of which are favored sturgeon prey (Gessner et al. 2010a–c, not paginate; Suciu and Qiwei 2010, not paginated). Anchovy landings declined by two thirds (Ivanov et al. 2000, p. 256).

In 1997, another jelly, *Beroe ovata* was deliberately introduced to the Black Sea as a biocontrol for *Mnemiopsis*. *B. ovata* is a predator of *Mnemiopsis* in their native range and has considerably reduced the abundance of *Mnemiopsis* in the Black sea (Shiganova et al. 2019, p. 434). Although *B. ovata* depresses the abundance of *Mnemiopsis*, there is an annual lag in the abundance of *B. ovata*, so there remains a short 1–2 month period each year in which *Mnemiopsis* has pronounced effects on the Black Sea food web, reducing sturgeon prey availability (Shiganova and Shirshov 2011, p. 89).

By 1999, *Mnemiopsis* was confirmed from the Caspian Sea, too (Ivanov et al. 2000, pp. 255–256). The species likely moved from the Sea of Azov through the man-made Volga-Don canal into the Caspian ecosystem (Ivanov et al. 2000, p. 255). The abundance of *Mnemiopsis* grew more than 200-fold from 1999 to 2009, peaking near 300 individuals per m^2 in the middle and southeastern portions of the Caspian (Kamakin and Khodorevskaya 2018, p. 174), although some authors report as many as 8085 *Mnemiopsis* per m^{-2} in the same region (Shiganova and Shirshov 2011, p. 36). *Mnemiopsis* tended to be least abundant in the cooler areas of the Caspian, including the north in winter and the central east, where cool upwelling currents chill the sea (Shiganova and Shirshov 2011, p. 40). The eastern region was first invaded to a considerable degree only in 2008 (Shiganova and Shirshov 2011, p. 41).

Mnemiopsis impacts on the Caspian ecosystem have been greater than those in the Black Sea (Shiganova and Shirshov 2011, p. 44). Caspian zooplankton abundance crashed by up to 90%, and mollusk larva—which grow into important sturgeon prey—disappeared from major sturgeon feeding grounds (Kamakin and Khodorevskaya 2018, p. 173; Shiganova and Shirshov 2011, p. 51). In the northern Caspian, crustacean biomass was halved as *Mnemiopsis* ate their planktonic larvae (Shiganova and Shirshov 2011, p. 52); in the south, crustaceans were nearly eliminated after having once been the dominant benthic taxa and sturgeon food item (Shiganova and Shirshov 2011, p. 53).

As in the Black and Azov Seas, Caspian Sea planktivorous fish declined heavily, due to both direct predation of eggs by *Mnemiopsis* and the loss of their zooplankton prey (Kamakin and Kohodoreskaya 2018, p. 175). In particular, several herring species (*Clupeonella* spp.) that previously formed a major component of sturgeon diets became rare (Shiganova and Shirshov 2011, pp. 53–59). For example, the Azerbaijian catch of three *Clupeonella* species fell from nearly 11,000 metric tons in 2002 to less than 1,000 in 2009 (Shiganova and Shirshov 2011, p. 58).

Releasing *B. ovata* in the Caspian is expected to have a similarly positive effect on *Mnemiopsis* as it did in the Black Sea (Shiganova and Shirsov 2011, pp. 105–110), but this action has not taken place yet, to our knowledge. Laboratory experiments suggest that *B. ovata*, the biocontrol, could survive in the central and southern Caspian Sea, but may be limited to the southern edge of the northern Caspian by the region's lower salinity (Shiganova and Shirshov 2011, p. 105). Still, the year after introduction, *B. ovata* is predicted to halve the *Mnemiopsis* abundance in just two weeks and to almost completely wipe it out within two months in the southern and middle Caspian (Shiganova and Shirshov 2011, p. 110). Thereafter, a short, early-season (July & August) bloom of *Mnemiopsis* followed by its control by *B. ovata* would be expected (Shiganova and Shirshov 2011, pp. 111–112). Sturgeon would likely benefit from recovery of the shellfish and planktivorous fish they eat (Shiganova and Shirshov 2011, pp. 111–113).

Roughly 60 other non-native species are present in the Caspian Basin (Shiganova and Shirshov 2011, p. 31). For instance, cyclic water level changes that have occurred in the Sea (see *Water level changes* below) have sometimes encouraged colonization of sturgeon feeding grounds by invasive shellfish and polychaete worms (Ruban et al. 2019, p. 390). Whether sturgeon consume these as readily as they do native invertebrates is not known. Regardless, no non-indigenous species are considered nearly as consequential for sturgeon as is *Mnemiopsis*.

Pollution

Most Ponto-Caspian rivers and all four seas discussed here have been polluted to a considerable degree. While the vast range of impacts of the many different contaminants and concentrations cannot be completely known or reviewed here, pollution tends to affect certain life stages of sturgeon more so than others. Eggs, embryos, young juveniles, and maturing and reproducing adults can all be sensitive to chemical effects (WSCS and WWF 2018, p. 50). Because sturgeon live close to the bottom of water bodies, they are exposed to organic pollutants (e.g., PCBs) and heavy metals that accumulate in sediments and in the bottom-dwelling animals that sturgeon feed on (Kasymov 1994 cited in He et al. 2017, p. 10; Billard and Lecointre 2001, p. 366; Kocan et al. 1996, p. 161). Heavy metals, organochlorine compounds, and hydrocarbons can all accumulate in sturgeon tissues where they can cause organ and reproductive failure (WSCS and WWF 2018, p. 50; Jarić et al., 2011, Luk'yanenko and Khabarov, 2005 and Poleksic et al. 2010 cited in Friedrich et al. 2019, pp. 1061–1062). Hermaphroditic fish have also been found in the Caspian and Black Sea basins due to endocrine effects of pollution (Gessner et al. 2010a, not paginated).

The Volga River was heavily polluted in the 1980s and 1990s with 500–1100% increases in the concentration of several heavy metals, some of which vastly exceeded Soviet and Russian maximum allowable concentrations (MACs; Makarova 2000 and Andreev et al. 1989 cited in Ruban et al. 2019, p. 389). Over 2300 metric tons of petroleum products, 35 metric tons of heavy metals, 21,000 metric tons of phosphorus and nitrogen, and many other pollutants were discharged to the Volga in 2001 alone (Fashchevsky 2004, p. 193), and the river water quality was said to be "unsatisfactory" for aquatic species (Moiseenko et al. 2011, p. 21).

Petroleum compounds were released from ships into the Volga at high rates in the late 1980s and accumulated in the river's sediments, surpassing MACs by 300–700% on Russian sturgeon spawning grounds (Andreev et al. 1989 and Khoroshko et al. 1997 cited in Ruban et al. 2019, p. 389). Heavy metals passed into sturgeon livers, kidneys, and spleens (Ruban et al. 2019, p. 389) and caused measurable physiological, reproductive, and morphological pathologies in bream *Abramis brama*, a species used as an indicator of pollution impacts on Volga river fish (Moiseenko et al. 2011, pp. 13–20). In sturgeon, eggshells were weakened and muscular abnormalitites were observed, too (Moiseenko et al. 2011, p. 2).

In contrast to the Volga, pollution is and has been a relatively limited problem in the Ural River. This is because the human population in the region is relatively sparse (Lagutov and Lagutov 2008, p. 246). Still, upstream portions of the river (especially within Cheliabinsk Oblast, Russia) may be highly polluted by industrial and agricultural inputs (Lagutov 2008, p. 148).

Pollution in the Kura River is not very well studied but is due to poorly treated municipal and industrial wastewater, agricultural and urban runoff, and mining residue from gold, copper, and iron (Bakradze et al. 2017, entire). Eutrophication appears not to be at emergency levels (Bakradze et al. 2017, p. 369). Arsenic, manganese, molybdenum, and lead concentrations are elevated in upstream portions of the Kura, relative to other regional rivers; however, the Mingachevir dam and reservoir prevent most such pollution from entering the lower 200-plus km of river (Suleymanov et al. 2010, pp. 306–311). The Terek and Sefid-Rud Rivers may not have problematic levels of pollution (Askhabova et al. 2019, p. 557; Askhabova et al. 2018, p. 213), but the evidence base is not as complete for these rivers.

In the Azov Basin, the Don River receives considerable volumes of heavy metals and petroleum byproducts (e.g., Dotsenko et al. 2018, entire; Sazykin et al. 2015, pp. 6–10), as do parts of the Kura (Qdais et al. 2018, p. 821–823). Since the 1970s, river inputs of nitrogen and phosphorus to the Azov have led to eutrophication in both the Don and Kuban (Strokal and Kroeze 2013, p. 190). However, the degree to which pollution and eutrophication are affecting sturgeon health in the Azov basin is poorly characterized. That said, in 1990, 55,000 sturgeon of unspecified species composition were found dead along the shores of the Azov Sea, apparently due to pollution (Gessner et al. 2010a, not paginated). The event very likely killed even more fish that did not wash ashore. Eutrophication is forecast to decrease between 2030 and 2050 for the Sea of Azov (Strokal and Kroeze 2013, p. 190).

The Dniester, Dnieper, and especially Danube Rivers in the northern Black Sea basin were all subject to large increases (300–700%) in nutrient and organic matter loading between the 1950s and 2000 (Bacalbaşa-Dobrovici 1997, p. 205; Strokal and Kroeze 2013, p. 188). These are typical of fertilizer runoff and wastewater discharge and caused eutrophication that increased turbidity and decreased the availability of sturgeon prey (Zaitzev 1992 and 1993 cited in Bacalbaşa-Dobrovici 1997, p. 205). Several thousand km^2 between the Danube and Dniester deltas (northwestern Black Sea) became hypoxic and unable to support fish between 1973 and 1990 (Bacalbaşa-Dobrovici 1997, p. 206). The dead zones killed many of the benthic mollusks that sturgeon prey on (Strokal and Kroeze 2013, p. 179). In 2000, 14,000 km^2 in the northern Black Sea (approximately 3% of the sea) was hypoxic, although nutrient inputs to the region have decreased since the 1970s and are forecast to continue decreasing (Strokal and Kroeze 2013, pp. 179 & 190). Clear data on more recent trends in Dnieper water quality are not available, to our knowledge.

Along the lower Danube River in Romania, a centuries-long history of deforestation has eroded riverbanks; consequently, water turbidity and sedimentation of sturgeons' gravel spawning grounds has increased (Bacalbaşa-Dobrovici 1997, p. 203). In other sturgeon species, high sediment loads limit sunlight that promotes egg development and can reduce the adhesion of sturgeon eggs to the substrate (Li et al. 2012, p. 557); very likely the Ponto-Caspian sturgeon experience similar effects of sedimentation. Overall, pollution impacts on sturgeon in the Danube are considered severe (Bănăduc et al. 2016, p. 144).

The 1986 Chernobyl Nuclear Power Plant disaster also contaminated much of the middle course of the Dnieper River (IAEA 2006, pp. 1–8). The power plant was built on the Pripyat River about 20 km from its confluence with the Dnieper. Today, the worst radioactive contamination remaining is in reservoirs and lakes and Dnieper River concentrations of the two most concerning radioisotopes—^{137}cesium and ^{90}strontrium—have fallen to below international safety standards (IAEA 2006, pp. 1–8). Thus, we do not believe radiological pollution currently has a strong impact on sturgeon.

In the southern Black Sea basin, including the Kizilirmak and Sakarya rivers, eutrophication has not been a major issue (Strokal and Kroeze 2013, p. 188), but heavy metals from industry and the removal of gravel for sand mining have degraded spawning grounds (Memiş et al. 2019, pp. 53–59). Fast-increasing human population density, fertilizer use, and sewage outflows suggest that the region will likely see increasing nutrient inputs and eutrophication soon (Strokal and Kroeze 2013, pp. 186–187). In the eastern part of the basin, the Rioni River, especially its lower and middle reaches, is impacted by wastewater, persistent industrial organochlorine compounds, and mining residues (GLOWS-FIU 2011, pp. 22–25), although the degree of the pollution and its effects on sturgeon is little known.

The sediments of the Evros River in the Marmara Sea basin is moderately to heavily polluted with heavy metals (Karaouzas et al. 2021, entire) and there are several industrial centers likely discharging other pollutants in the river's upstream catchment (Nikolaou et al. 2008, pp. 309–310). However, it is unclear the extent to which this pollution contributed to the extirpation of stellate sturgeon from the river.

The Amu-Darya and Syr-Darya Rivers, which formerly entered the Aral Sea, were heavily polluted with agricultural and industrial chemicals from the 1970s to 1990s (Zholdasova 1997, pp. 374–375), as the ship sturgeon population was extirpated (Aladin et al. 2018, p. 2077; Ermakhanov et al. 2012, p. 4). Concentrations of phenols, nitrates, and heavy metals were all above Soviet MACs in the lower and middle Amu-Darya in 1989–1990, with especially polluted conditions at downstream locations. There, several such contaminants were present at dozens of times their MACs (Zholdasova 1997, p. 375). The massive evaporation that occurred in the Aral Sea and its inlets greatly increased dissolved mineral contents and salinity (up from 10 to 38 ppt in 1961) to levels avoided by and even intolerable to sturgeon.

The Syr-Darya remains heavily polluted today. Intensive use of fertilizer and pesticides in the basin, especially for cotton farming, have made the water unsafe for fisheries and agriculture (Taltakov 2015, pp. 137–138). Water withdrawals for irrigation have caused increased salinity of the remaining river water, too (Taltakov 2015, p. 137). As an indication of the level of water contamination that remains, some warn that crops grown with Syr-Darya water are carcinogenic and should be burned, not eaten, and that it will take over a decade to have safe water in the river, if and when cleaning begins (Taltakov 2015, pp. 135–138).

It is not likely that meaningful restoration of the Aral Sea will occur in the near future; the region's agriculture is too dependent on continued irrigation, pesticide, and fertilizer use (Whish-Wilson 2002, p. 32). That said, beginning in the early 1990s, there was a limited decrease in pesticide concentrations in what water remained in the Amu-Darya (Zholdasova 1997, p. 375).

Water level changes

The Caspian Sea has undergone fluctuating water level changes which have affected the basin's sturgeon. Between 1930 and 1977, the water level dropped approximately 3 m (Fig. 3.14; Chen et al. 2017, p. 6997; Dumont 1998, p. 45) mainly due to reduced rainfall, increased evaporation, and reduced runoff into the Caspian Sea (Chen et al. 2017, pp. 6998–6999).

The water level drop and consequent increase in salinity caused mollusk populations to decline locally by up to 90% (Dumont 1998, p. 51). The reduction in foraging grounds for sturgeon compounded the negative impacts of overfishing and lost connectivity due to dams (especially the Volgograd; Ruban and Khodorevskaya 2011, p. 204). The impacts of these water level fluctuations are greatest in the north Caspian because this section of the sea is shallow to begin with (Shiganova and Shirshov 2011, p. 21).

From 1978 to 1995, the water level recovered by about 2.5m, allowing a small bump in foraging area and an increase in sturgeon recruitment (Fig. 3.14; Chen et al. 2017, p. 6997; Ruban and Khodorevskaya 2011, p. 205; Dumont 1998, p. 45). However, since 1995, the Caspian Sea level has again been falling steadily (Fig. 3.14; Chen et al. 2017, p. 6997).

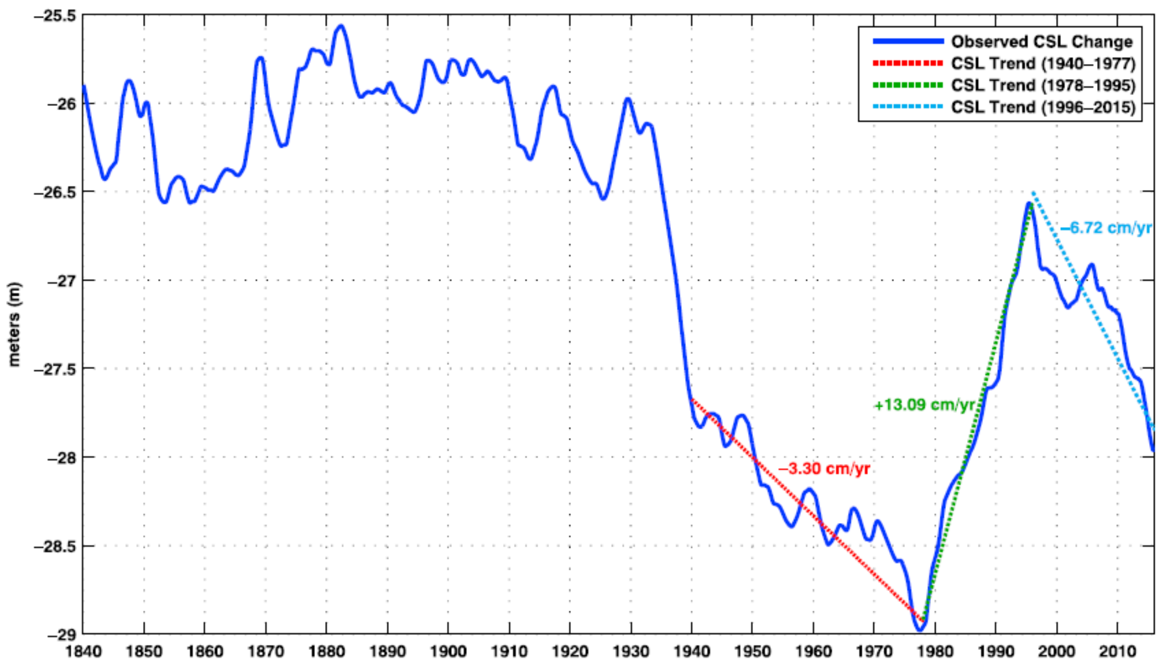


Figure 3.14—Change in Caspian Sea Level (CSL) from 1840 to 2015. Figure reproduced from Chen et al. 2017 (Fig. 2).

Disease and predation

There is no natural predator of adult Ponto-Caspian sturgeon (Lagutov and Lagutov 2008, p. 205) and disease is not nearly as pressing a threat to Ponto-Caspian sturgeon as overfishing and dams are at present (WSCS and WWF 2018, entire; Reinartz and Slavcheva 2016, entire; Gessner et al. 2010a–c, Suciu and Qiwei 2010, not paginated). However, several dozen species of invertebrates parasitize sturgeon, sometimes infecting a very high proportion of fish in a population. While generally not fatal, their effects on sturgeon health are poorly known (Bauer et al. 2002, entire). We briefly describe the most salient diseases and paraites; although some were historically important threats, these are not presently considered major factors in the decline of Ponto-Caspian sturgeon.

Parasites and pathogens

In 1934, 90 stellate sturgeon were transplanted into the Aral Sea, where only the ship sturgeon was native from among the four Ponto-Caspian taxa (Bauer et al. 2002, p. 422). The stellate sturgeon brought with them the monogeneid parasite *Nitzschia sturionis*, to which ship sturgeon lacked immune defenses (Bauer et al. 2002, pp. 422–423). Up to 400 1-cm-long *N. sturionis* can infest a fish's gills and mouth, where they consume the fish's blood. *N. sturionis* proceeded to infect and decimate the ship sturgeon population. Exactly how many ship sturgeon were killed is unclear, but mortality was significant, as people reported fish jumping out of the water and dying on the adjacent beaches (Bauer et al. 2002, p. 422).

Polypodium hydriforme is the sole known intracellular parasite in the phylum Cnidaria (which includes sea jellies and corals) and infects at least 12 sturgeon species globally (Raikova 2002, p. 405). The parasite is present throughout the Black and Caspian Sea basins and infects eggs of Russian, ship, and stellate sturgeon (Raikova 2002, p. 406). It very likely also infects Persian sturgeon eggs, as this species may have been considered part of the Russian sturgeon taxonomic complex by Raikova (2002).

P. hydriforme infection occurs when its free-living stage infects young sturgeon, possibly as early as their larval stage (Raikova 2002, pp. 412–413). It infects and kills sturgeon oocytes, consuming the yolk and preventing sturgeon embryo development (Raikova 2002, pp. 412–413). Importantly, although a large proportion of adult female sturgeon may be infected (range 1–100% depending on sampled species, location, and time), relatively few eggs per female tend to be affected (usually just several dozen per female, and never reported at greater than 25% of eggs in the species assessed here; Raikova 2002, p. 406). Given the high fecundity of Ponto-Caspian sturgeon and the low survival of first-year individuals (e.g., Jaric and Gessner 2013, pp. 485–486; Jager et al. 2001, p. 351), it is unlikely that such low mortality of eggs has a significant impact on reproductive output.

Reproductive maladies

Several different malformations and disorders associated with sturgeon reproduction have, at times, been moderately common in the Ponto-Caspian species. Nearly 7% of stellate sturgeon and 2% of Russian and Persian sturgeon in the Caspian Sea were intersex in the late 1980s (Ruban et al. 2019, p. 393). This condition is the development of both male and female reproductive organs (oocytes and testes), although such fish may be sterile. Reproductive pathologies may be linked to endocrine disrupting pollutant exposure, but some unknown prevalence of intersex may be natural in fish populations, too (Bahamonde et al. 2013, entire).

Also in the late 1980s, 20% of female Russian and Persian sturgeon and 10% of female stellate sturgeon displayed abnormal egg development in the Volga basin (Ruban et al. 2019, p. 393). Egg nuclei dissolved and cytoplasm irregularities developed, leading eggs to be resorbed without being laid (Ruban et al. 2019, p. 393). Structural anomalies in egg membranes were observed in Russian, Persian, and stellate sturgeon collected for aquaculture as early as the 1960s; by 1998 these were present in 35% of Russian and Persian sturgeon and 25% of stellate sturgeon (Ruban et al. 1960, p. 393). In affected Russian and Persian sturgeon, 11% of their eggs were malformed, whereas this number was 25% in stellate sturgeon (Ruban et al. 1960, p. 393). It is unclear whether these rates are sufficient to cause significant, additive mortality, i.e., above and beyond the already very low survival rates of larva and fry (Jaric and Gessner 2013, pp. 485–486; Jager et al. 2001, p. 351).

Climate change

Global climate models (Karger et al. 2018, not paginated; Karger et al. 2017, entire) indicate that by 2041–2060 mean annual air temperature in the Caspian, Black, and Aral Sea basins will increase by 2–3°C relative to the mean for the period 1979–2013 (Fig. 3.15, Table A2.2; see Appendix II for details of the calculations and models used). Precipitation projections over the same time period are less certain. The eastern Aral Sea basin may see slightly more precipitation and the region between the Black and Caspian Seas is expected to become drier, as is that south of the Black Sea (Fig. 3.15, Table A2.2). However, projections for most of the region indicate little directional change (Fig. 3.15, Table A2.2).

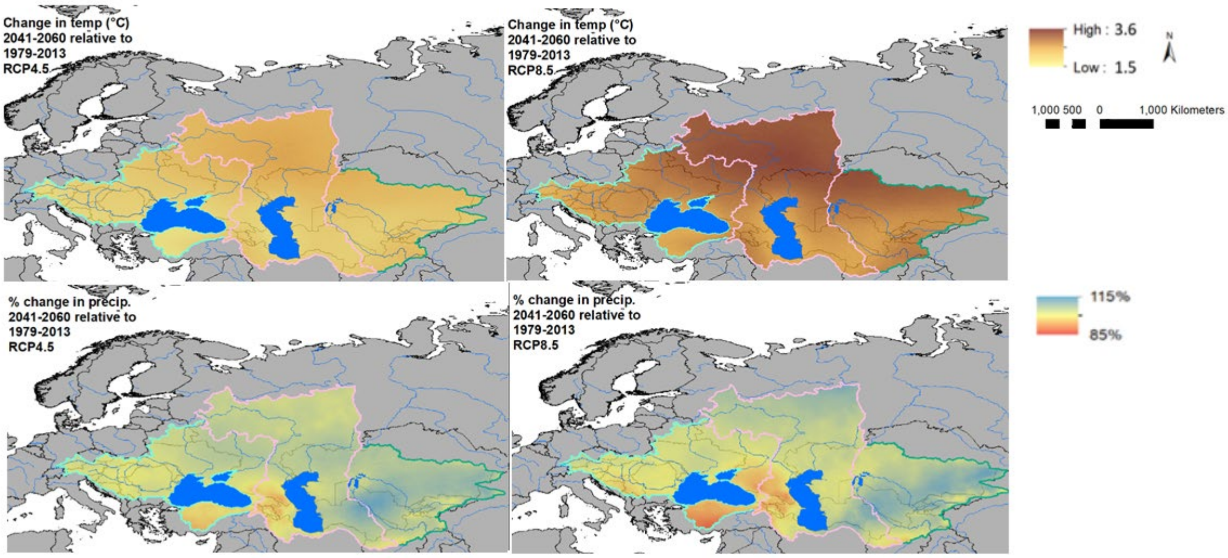


Figure. 3.15—Projected change in mean annual air temperature (top) and mean annual precipitation (bottom) for 2041–2060 in the Black, Azov, Caspian, and Aral Sea basins. Temperature data are increases relative to the 1979 – 2013 baseline. Rainfall data are percent of the 1979 – 2013 baseline rainfall (100% indicates no change). Left panels show data for the IPCC's RCP4.5 scenario, a lower-emissions future in which renewable energy, greater energy efficiency, and carbon capture and storage are more widely implemented (Thomson et al. 2011, pp. 77). Right panels show projections from the RCP8.5 scenario, a "high-emission business as usual future" i.e., towards the upper end of what might occur without climate change mitigation policy (Riahi et al. 2011, pp. 54). Data from Karger et al. (2017 & 2018).

As a result of warming air temperatures, water in the remaining accessible spawning grounds will also become warmer, with potentially positive or negative effects on sturgeon reproduction. Surface waters (0–2m depth) warm quickly in response to air temperature (McCombie 1959, pp. 254–258) and air temperature in upstream regions of the Volga have warmed by up to 0.5°C per decade since 1971 (Bui et al. 2018, p. 499). The lower Danube River is projected to warm by up to 1°C by the year 2100 relative to 1961–1990 (van Vliet et al. 2013, p. 5). For deeper waters where sturgeon breed and feed, the exact concurrence between regional warming of air temperatures and local warming of water is uncertain. This depends on factors including water depth, currents, groundwater input, and the degree of warming in upstream regions.

The Ponto-Caspian sturgeon spawn at 8–16 °C, except Persian sturgeon, which prefer warmer water of 16–25 °C (Gessner et al. 2010a, not paginated; Gessner et al. 2010b, not paginated, Gessner et al. 2010c, not paginated; Suciu and Qiwei 2010, not paginated). Increased water temperatures could eventually halt reproduction. Juvenile sturgeon may also struggle to survive in water above 25°C (WSCS and WWF 2018, p. 51). For the most northerly Ponto-Caspian rivers, the current maximum temperatures do not approach this level (e.g., Volga: Bui et al. 2018, p. 499), but the central and southern rivers often do (e.g., Danube and Sefid-Rud: Gessner et al. 2010c, not paginated; Bonacci et al. 2008, p. 1016).

In contrast, warming might speed Ponto-Caspian sturgeon growth and maturation, as for other sturgeon (Krykhtin and Svirskii 1997, p. 237). Warmer water can even cause kaluga sturgeon

(*Huso dauricus*), a species that lives in eastern China and Russia's Amur River, to reproduce a full year earlier (Krykhtin and Svirskii 1997, pp. 234–235). In Lake sturgeon (*Acipenser fulvescens*), a North American species, juveniles from cohorts that hatched in years with more rapid spring warming have higher relative survival than those that developed in slow-to-warm springs (Nilo et al. 1997, p. 778). Although similar benefits are likely for Ponto-Caspian sturgeon, they will have only minimal impacts on population resiliency, given the ongoing and much greater negative impacts of dams and overfishing.

It is also uncertain whether increasing temperatures *per se* are the aspect of climate change to which Ponto-Caspian sturgeon are most sensitive. For instance, in the Caspian basin, increased evaporation is expected to continue causing a decrease in sea level, with consequent loss of shallow feeding areas (Chen et al. 2017, p. 6999), although increased rainfall may partially counterbalance this net decline in some years (Chen et al. 2017, p. 6999). Warmer water also holds less oxygen, and other sturgeon species outside the Ponto-Caspian region are projected to experience high enough water temperatures, and consequently low enough oxygen concentrations, to limit habitat availability as climate change progresses (Lyons et al. 2015, p. 1508; Hupfeld et al. 2015, pp. 1197–1200). We are not aware of studies assessing this possibility for Ponto-Caspian sturgeon, specifically.

Several rivers in the Ponto-Caspian sturgeons' ranges are fed by either snowmelt or glaciers. In the case of the Amu-Darya River, climate change progression is expected to speed glacier melting, creating an increase in year-to-year variability of river flow over the next few decades, followed by a decrease in flow when the glaciers are exhausted and snow is less abundant, possibly by the end of this century (White et al. 2014, p. 5274; Savitskiy et al. 2008, pp. 337–338). For the Syr-Darya, which is primarily snow-fed, increased temperatures are projected to limit snowfall and speed snowmelt, leading to reduced river flow and an earlier spring peak in flow (Savitskiy et al. 2008, pp. 337–338). Still, dams and irrigation are by far the main causes of flow decrease in the Aral Sea basin (White et al. 2014, p. 5268).

The Ural and Volga Rivers have headwaters far north of the Caspian Sea (Fig. 2.5). Climate models project these northern regions to receive slightly more precipitation in the coming decades, but this may be offset by increased evaporation due to higher temperatures (Fig. 3.15; Frederick and Major 1997, p. 9; Schneider et al. 2013, p. 325). Summer flow volumes have recently been falling and are projected to become yet lower in this region of Europe. In the presently highest-flow months (December–February) flows are projected to increase, albeit with high variability across locations (Schneider et al. 2013, p. 335).

Restocking

In response to the long-term declines in Ponto-Caspian sturgeon fishery stocks, massive restocking efforts have been made in some parts of their range (Table 3.1). Approximately 3.3 billion sturgeon (all species) were released into the Caspian basin between 1954 and 2011 (examples is Table 3.1; Khodorevskaya and Kalmykov 2014, p. 578). Nearly 2.2 billion of these were from Russian production alone (Khodorevskaya and Kalmykov 2014, p. 578). One source indicated a total of 21 or 23 farms producing Russian, ship, and stellate sturgeon in the Caspian region as of 2014, with about half in Russia, one third in Iran, and fewer in Azerbaijan and Kazakhstan (Khodorevskaya and Kalmykov 2014, p. 578).

Although widely practiced and at least partially responsible for preventing extinction of Ponto-Caspian sturgeon to date, restocking is far from a perfect solution. In general, restocking is thought to produce "put-and-take" fisheries, where fish are released and then mostly caught before reproducing (e.g., Vecsei 2001, p. 362; WSCS and WWF 2018, pp. 18 & 42). Such an optimistic outcome is unlikely (WSCS and WWF 2018, p. 6; Gessner et al. 2010a–c, not paginated) and the frequent use of non-native species and stocks further decreases restoration success (Ludwig 2006, p. 7).

In addition, restocked and translocated fish may not have the necessary instincts to migrate to the "correct" river, if they are not derived from the local stock (Lagutov and Lagutov 2008, p. 262). And, most fish released are fingerlings, one to several months old (Gessner et al. 2010a, not paginated), which naturally have extremely low first-year survival rates (around 1 in 2000; Jaric and Gessner 2013, pp. 485–486; Jager et al. 2001, p. 351).

Release of fish native to one region or river into another can dilute locally adaptive traits when wild-born native fish breed with these captive individuals (WSCS and WWF 2018, p. 50). Such hybridization can reduce the resiliency, and representation of local populations if introduced individuals are maladapted to local conditions and can be due to interspecific or intraspecific, inter-stock hybridization.

Translocation of fertilized eggs from the Caspian Sea to the Azov Sea likely diluted the local stellate sturgeon gene pool in the 1990s and early 2000s (Suciu and Qiwei 2010, not paginated). For ship sturgeon, only Caspian stocks are available in captivity, not Black or Aral Sea basin fish (WSCS and WWF 2018, p. 36). This could make their restoration in the Black, Azov, and Aral Seas more difficult, if local adaptations and migration instincts limit the utility of captive-reared fish in these parts of the range. Stocking of the Don and Kuban Rivers with stellate sturgeon from Caspian stocks that naturally have lower population growth rates than the Azov's stellate sturgeon similarly reduces the species' representation (Tsvetnenko 1993, p. 1).

Without addressing the difficulties inherent in current restocking programs, and moreover the root causes of sturgeon declines, restocking cannot be expected to establish resilient, self-sustaining populations (Friedrich et al. 2019, p. 1064). Indeed, for watercourses like the Danube, which have dozens of dams, some experts believe it is simply "fiction" to consider restoration of the species and their migration to upstream reaches of such rivers (Friedrich et al. 2019, p. 1065). Restoration of downstream reaches through restocking and facilitated dam passage is more feasible (Friedrich et al. 2019, p. 1065).

Still, existing infrastructure for large-scale commercial production of sturgeon could possibly be employed to provide fish for restocking, although significant participation of commercial farms in sturgeon conservation remains rare (Jahrl and Streibel-Greiter pers. comm. 2020; WSCS and WWF 2018, pp. 31 & 59; WSCS and WWF 2017, p. 13). Nonetheless, several Ponto-Caspian countries (Russia, Armenia, Iran, Bulgaria, Azerbaijan, Hungary, and Germany) rank in the top fifteen producers of farmed sturgeon globally. Their 2017 production of all sturgeon species ranged from 287 tons (Germany) to 6,800 (Russia; Bronzi et al. 2019, p. 259). Only China (78,000 metric tons) produced more than Russia in 2017 (Bronzi et al. 2019, p. 259). Russian sturgeon accounts for 20% of farmed caviar production, globally (Bronzi et al. 2019, p. 261). France recently approved the production of Russian, stellate, and Persian sturgeon, so it is expected that farming of these species will soon increase there (Bronzi et al. 2019, pp. 263 – 264).

Table 3.1—A non-exhaustive list of example Ponto-Caspian restocking activities and volumes. As indicated in the main text, all or nearly all of these employed small fish less than one year old.

Species	Volume	Year	Location	Citation
Russian	46 million	1978 – 1989	Volga	Ruban and Khodorevskaya 2011, p. 205
	2 – 5 million	1994–1998	Unknown	Gessner et al. 2010a, not paginated
Ship	80,000 – 1,000,000 ranched and released annually	unknown	Iran	Gessner et al. 2010b, not paginated
Persian	25 million	1998	Iran	Abdolhay and Baradaran Tahouri 2006 cited in Gessner et al. 2010c, not paginated
	10 million	2008	Iran	Gessner et al. 2010c not paginated
Stellate	12 million	2012	Russia	Suciu and Qiwei 2010, not paginated
	8.1 million	2012	Azerbaijan, Iran, Kazahkstan	Suciu and Qiwei 2010, not paginated
	18 million	1978 – 1989	Volga	Ruban and Khodorevskaya 2011, p. 205
	Unknown, using Caspian stocks	1961–1986	Don & Kuban	Billard and Lecointre 2001, p. 374
	20 million	1998 – 2005	Ural	Lagutov and Lagutov 2008, p. 261

Extra-territorial introductions

Ship sturgeon were introduced to the upper reaches of China’s Ile River in the 1960s (Gessner et al. 2010b, not paginated) and are now listed as a class II species under the country’s Wild Animal Protection Law, which restricts use to those cases permitted by regional, provincial, or local government (Harrish and Shiraishi 2018, pp. 46–47). Most approved fishing is for research or monitoring (Harris and Shiraishi 2018, p. 47). Fines for violating these statues are between two and 10 times the value of the catch (Harris and Shiraishi 2018, p. 47).

Russian sturgeon are farmed in Uruguay and sporadic escapes followed by dispersal have led to a small number of observations of the species in the rivers of Uruguay, Argentina, and Brazil (Chuctaya et al. 2018, p. 397; Demonte et al. 2017, p. 1). Similarly, a very small number of Russian sturgeon have been caught in the Polish Baltic Sea basin since first being documented there in 1968 (Skóra and Arciszewski 2013, p. 365). There is no indication that the species is reproducing in these areas.

Gene banking and cryopreservation

The cryopreservation of Russian and ship sturgeon and the banking of their genetic material is underway in Russia and Iran (Gessner et al. 2010a,b, not paginated). Such measures are more indicative of the presently high level of extinction threat to the Ponto-Caspian sturgeon than of conservation investments likely to allow the species' restoration in the near term. Commercial-scale farming capacity may be important to long-term restoration efforts than using preserved genetic stocks.

Chapter 4—Current condition of the species

The current range-wide outlook for all four taxa of Ponto-Caspian sturgeon is bleak, but recovery is not yet impossible, if major efforts are made (Fauna and Flora International 2019a, p. 2; Ruban and Khodorevskaya 2011, p. 206). The intensive poaching since the 1990s means very little natural reproduction contributes to the maintenance of wild populations; remaining stocks have long been stood up by massive inputs of farmed juveniles (Ruban and Khodorevskaya 2011, p. 205; Vecsei 2001, p. 362). As of October 2020, all four taxa are listed as "Critically Endangered" on the IUCN Red List for an "observed or inferred" global decline of at least 80% over the last ten years or three generations (24–66 years, depending on the species; Table 2.2) with ongoing threats (Gessner et al. 2010a; IUCN 2000, p. 16). This category is the most imperiled state IUCN assigns a species before considering it extinct in the wild. Although IUCN's rating system is not directly comparable to that used for ESA status determination, the Red List provides a readily accessible, expert-validated assessment of conservation threat.

Existing and prior conservation measures have been wholly unsuccessful at curtailing and reversing the decline of Ponto-Caspian sturgeon populations (Khodorevskaya and Kalmykov 2014, p. 582). As such, mature Ponto-Caspian sturgeon rarely survive harvesting to reproduce multiple times (Ruban et al. 2019, p. 391), whereas those living to a natural death after full life expectancy could easily reproduce 8–10 times, if not more (Table 2.2).

In the Caspian basin, as of 2010, Russian and stellate sturgeon populations are, respectively, roughly 30% and 10% of their size in 1970 (Fig. 4.1). As of 2008, nearly 70% of the basin's sturgeon (all species, including beluga and sterlet) were Volga River individuals, nearly 30% were Ural River migrants, and the other more southern Caspian rivers accounted for little more than 1% (Lagutov and Lagutov 2008, p. 198). The total abundance of spawning sturgeon in the basin (all species) was over 3.5 million in 1991 but only about 500,000 in 1997 (Khodorevskaya et al. 1997, cited in in Billard and Lecointre 2001, p. 374). Unfortunately, some rivers have not been comprehensively survived in many years (Lagutov and Lagutov 2008, p. 203), but the best available information does not indicate any substantial increases in population size for any Ponto-Caspian sturgeon species in any Caspian Basin River since then. Thus, it is likely that fewer than 5,000 reproductive fish (male and female, of all four taxa assessed here) were present in the Kura, Terek, and Sefid-Rud combined.

In the Black and Azov Sea basins, only the Danube, Rioni, and possibly the Kuban, and Sakarkya Rivers contain wild breeding populations of sturgeon (Fauna and Flora International 2019a, p. 2; WSCS and WWF 2018, p. 3). All eastern Black Sea sturgeon populations are on the verge of extirpation (Fauna and Flora International 2019a, p. 2). The conservation measures taken to date have been ineffective (WSCS and WWF 2018, p. 6; Khodorevskaya & Kalmykov 2014, p. 582; Fashchevsky 2004, p. 196) and according to one pair of experts "The sturgeon populations of the Sea of Azov are doomed to extinction with no chance for natural restoration" (Lagutov and Lagutov 2008, p. 252).

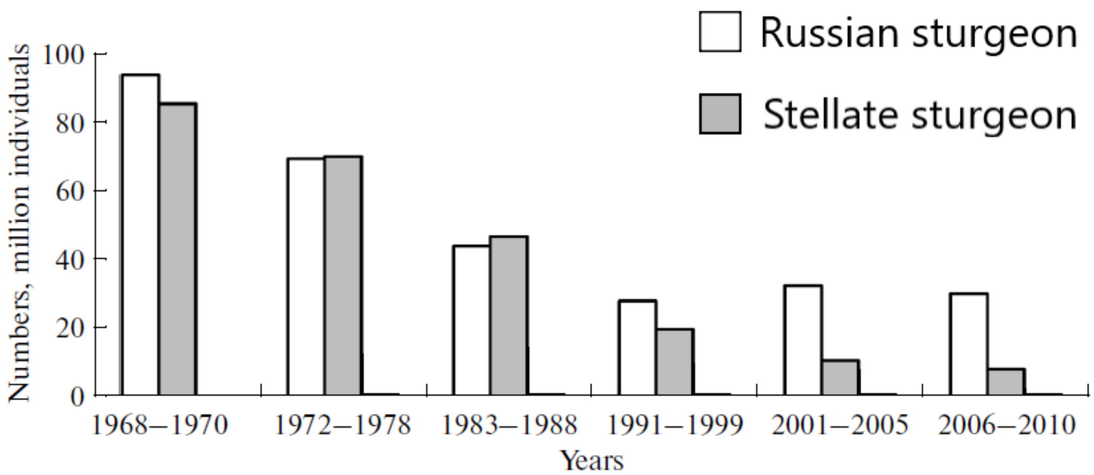


Figure 4.1—Abundance of Russian and stellate sturgeon in the Caspian Sea from 1968–2010. Adapted from Khodorevskaya and Kalmykov 2014, p. 578.

We used the resiliency criteria and definitions of redundancy and representation described in Chapter 2 to evaluate the current condition of each of the four Ponto-Caspian sturgeon taxa. The current scores for two of the resiliency criteria—connectivity and habitat quality—are presented in Table 4.1 and are constant across sturgeon taxa. We added these scores to the reproductive success and abundance scores (the third resiliency criterion) to determine the total resiliency of each population.

Table 4.1—Connectivity and habitat quality resiliency scores.

	Connectivity	Habitat quality		Connectivity	Habitat quality
Azov Sea			**Caspian Sea**		
Don River	1[1]	1–2[11, 12]	Volga	1[1]	1[20]
Kuban River	1[1]	1–2[16]	Ural	2[1, 5]	2[5]
			Kura	1–2[1]	1–2[7, 8]
Black Sea			Terek	1–2[6]	2–3[9, 10]
Danube	1[1]	1[17]	Sefid-Rud	1[1]	2–3[15]
Dnieper	1[1]	1–2[18, 19]			
Southern Bug	1[4]	1–3 (unknown)	**Aral Sea**		
			Syr-Darya	1[3]	1[6]
Dniester	1[1]	1–2[18, 19]	Amu-Darya	1[2]	1–2[2]
Rioni	1[1]	1–2[13]			
Kızılırmak	1[1]	2–3[14]	**Sea of Marmara**		
Sakarya	1[1]	1–2[14]	Evros River	1[1]	1–2

References: [1]GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502; [2]Zholdasova 1997, p. 374–375; [3]Ermakhanov et al. 2012, p. 6; [4]Bezsonov et al. 2017, p. 25; [5]Lagutov and Lagutov 2008, p. 197; [6]Taltakov 2015, pp. 137–138; [7]Bakradze et al. 2017, entire; [8]Suleymanov et al. 2010; Table 4 & pp. 309–311; [9]Askhabova et al. 2019, p. 557; [10]Askhabova et al. 2018, p. 213; [11]Dotsenko et al. 2018, entire; [12]Sazykin et al. 2015, pp. 6–10; [13]GLOWS-FIU 2011, pp. 22–25; [14]Memiş et al. 2019, pp. 54–57; [15]Rafiei et al. 2017, entire; [16]Qdais et al. 2018, p. 821–823; [17]Bănăduc et al. 2016, p. 144; [18]Bacalbaşa-Dobrovici 1997, p. 205; [19]Strokal and Kroeze 2013, p. 188; [20]Ruban et al. 2019, pp. 389–390.

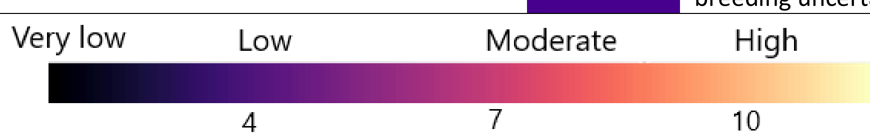
The connectivity of all focal rivers, except the Southern Bug, is impacted by dams and other water control structures (Chapter 3; GRanD 2019, not paginated; 4Bezsonov et al. 2017, p. 25; Lehner et al. 2011, entire; Fashchevsky 2004, pp. 183–184). Only the Ural and possibly the Kura and Terek have long undammed sections remaining along their downstream stretches (GRanD 2019, not paginated; Lehner et al. 2011, entire; Taltakov 2015, pp. 137–138). This leaves a greater proportion of spawning habitat available to migrating sturgeon before their upstream progress is halted. All other rivers were scored as having low connectivity (1 point).

Habitat quality and its impacts on sturgeon health and prey availability was more variable across focal rivers but was also the criterion with the most uncertainty (Table 4.1). We scored this criterion according to the literature cited and summarized for each river in the Chapter 3 sections on pollution, but as noted there, it is often unclear the degree to which measured water pollution is impacting sturgeon or their prey. Recent data are also often lacking. Thus, we allowed a range of scores where we could not confidently assign a river's habitat quality to a single point level.

Russian sturgeon

Table 4.2—Current resiliency and redundancy of Russian sturgeon

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency	Notes
Azov Sea					No spawning; Only restocked fish[1]
Don River	0–1[2]	1	1–2	**2-4 (poss. extirpated)**	Not recorded in 10+ years as of 2018[2]; if present, persists only from restocking[2].
Kuban River	0–1[2]	1	1–2	**2-4 (poss. extirpated)**	"Put and take" fishery as of 2001[3]; Not recorded in 10+ years as of 2018[2]; if present, persists only from restocking[2].
Black Sea					Very rare, few spawning sites available due to dams[1];
Danube	2[1, 2, 8]	1	1	**4**	No records in 10+ years as of 2018[2]; farmed releases ongoing[2].
Dnieper	1[2]	1	1–2	**3-4**	no records in 10+ years as of 2018[2]; farmed releases ongoing[2].
Southern Bug	1[3]	1	1-3; unknown	**3-6**	"severely depleted" in 2001[3]
Dniester	0[2]	1	1–	**Extirpated**	
Rioni	2[2, 4, 7]	1	1–2	**4-5**	Reproducing[2]; only Eastern Black Sea river with any sturgeon spawning[4].
Kızılırmak	0[1, 2]	1	2–3	**Extirpated**	no records in 10+ years as of 2018[2];
Sakarya	1[10]	1	1–2	**3-4**	Small number of fish caught, no evidence of reproduction in 2014
Caspian Sea					70% spawning grounds lost since 1950 due to dams[1]
Volga	2[1, 3]	1	1	**4**	Spawns, but 88% decline in spawners 1992-2002 vs. 1965-1975[1]; was only large run as of 2001[3]
Ural	2[1]	2	2	**6**	
Kura	1[1, 9]	1–2	1–2	**3-5**	Likely hasn't spawned since 1983[1,5]
Terek	1[1,5]	1–2	2–3	**4-6**	Likely hasn't spawned since 1983[5]
Sefid-Rud	1–2[6]	1	2–3	**4-6**	Present, but 99% biomass decline in Iranian Caspian waters 1990-2009; breeding uncertain[6]



Redundancy score: 6. 10–12 extant populations, all in low or very low condition.

References: [1]Gessner et al. 2010a, not paginated; [2]WSCS and WWF 2018, pp. 10–12 & pp. 30–31; [3]Vecsei 2001, p. 362; [4]Flora & Fauna International 2019a, p. 2; [5]Lagutov & Lagutov 2008, p. 223; [6]Tavakoli et al. 2018, p. 381 & Fig. 6;

[7]Reinartz and Slavcheva 2016, pp. 44–45; [8]Reinartz et al. 2020e, p. 6; [9]Ruban and Khodorevskaya 2011, p. 202; [10]Memiş et al. 2019, pp. 53–58.
See Table 4.1 for connectivity and habitat quality references.

Russian sturgeon redundancy is moderate, with at least 10 of 14 focal rivers retaining the species, but all extant population are believed to have low (scored 5 – 6) or very low (1–4) resiliency. It is likely that no self-sustaining populations remain. As of 2005, total genetic diversity remained surprisingly high in Russian sturgeon, although there was little differentiation between populations (Timoshkina et al. 2009, pp. 1103–1105; Doukakis et al. 2005; pp. 458–459). A small population and its genes, was separated from the rest of the species when it was trapped upstream of the Iron Gates II Dam on the Danube River (Billiard and Lecointre 2001, p. 373). Representation is likely moderate, but with considerable uncertainty.

Caspian basin

The Volga and Ural spawning populations are now a small fraction of their previous sizes. Estimates from fishery catch volume and the number of spawners entering the Volga River indicate approximately 90% declines between 1964 and 2009 (Gessner et al. 2010a, not paginated). However, as of 2008, the Ural sturgeon stocks had not been comprehensively assessed in over two decades (Lagutov and Lagutov 2008, p. 203). Although there is still some natural reproduction occurring in the Ural, most sturgeon trying to spawn in there are caught in the estuary (Reinartz and Slavcheva 2016, pp. 44–45). In low-flow years (e.g., 2006), no sturgeon spawn in the Ural (Lagutov and Lagutov 2008, p. 204).

Natural reproduction also still occurs in the Volga River, but nearly all spawning females are captured each year below the Volgograd Dam (Reinartz and Slavcheva 2016, pp. 44–45). Only about 10,000 Russian sturgeon migrated up the Volga annually between 2003 and 2007 (Veschev et al. 2008 cited in Khodorevskaya & Kalmykov 2014, p. 580), well below the 200,000 females supposedly needed annually for a stable population at the river, according to species experts, although it is not clear how this minimum requirement was determined (we contacted the lead author for clarification, but did not receive a reply; Khodorevskaya & Kalmykov 2014, p. 581). Between 1995 and 2010 alone, Russian sturgeon biomass in the river decreased by over 80% (Lepelina et al. 2010 cited in Khodorevskaya and Kalmykov 2014, p. 578).

As of 2011, reproductive females were only about 10% of mature fish in the Volga (Fig. 4.3; Safaraliev et al. 2012 and Konopleya et al. 2007 cited in Khodorevskaya and Kalmykov 2014, p. 578). Females rarely live long enough to spawn more than once (Fig. 4.2; Ruban et al. 2019, p. 391) and likely also lay fewer eggs than they used to (Ruban et al. 2019, p. 392), further limiting reproductive potential.

As a result of the population declines and demographic changes, many fewer larva migrate out of the Volga River than did historically (Ruban et al. 2019, pp. 392–393). By one estimate, annual recruitment of Russian sturgeon juveniles from the Volga fell by over 97% between 1966 and 2011 (Khodorevskaya and Kalmykov 2014, p. 579).

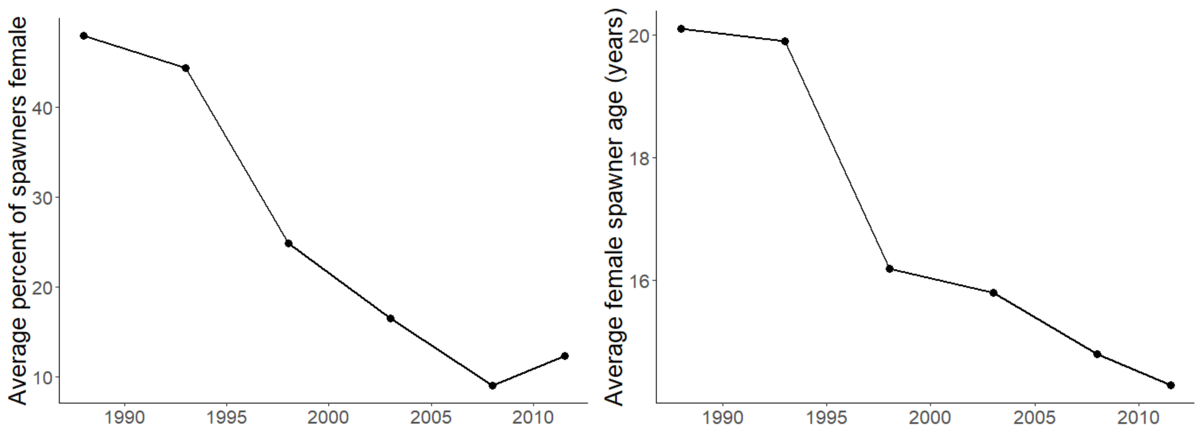


Figure 4.2—The average percent of Russian sturgeon spawners that were females (left) and the average age of those spawners (right) in the Volga River. Data from Ruban et al. 2019, p. 392. No measure of uncertainty within sampling time points was given.

As mentioned above, the Caspian sturgeon populations outside the Volga and Ural are very small (about 1% of Caspian basin individuals; Lagutov and Lagutov 2008, p. 198). In Azerbaijan, the Kura River's Russian sturgeon are nearly depleted (Ruban and Khodorevskaya 2011, p. 202) and whether they still spawn there is uncertain, at best (Gessner et al. 2010a). Some sources indicate no Russian sturgeon have spawned in the Kura or Terek River (which flows through Georgia and the Russian republics of Chechnya and Dagestan) since 1983 (Lagutov & Lagutov 2008, p. 223).

Russian sturgeon biomass in Iran's Sefid-Rud (and smaller rivers) declined from nearly 2000 metric tons biomass in 1990 to less than 20 in 2009, a 99% decrease (Tavakoli et al. 2018, p. 381 & Fig. 6). The rate at which commercial fishermen caught Russian sturgeon as bycatch provides another useful index of their condition in the region. Whereas 0.58 Russian sturgeon were caught for every trawl in this southern Caspian region in 2001, only 0.03 per trawl were caught by 2010 (Moghim et al. 2006 and Tavakoli 2013 cited in Tavakoli et al. 2018, p. 383). Still, Iranian fishermen bring Russian sturgeon to 47 caviar processing plants (Tavakoli et al. 2018, p. 379) and only about 65% of Russian sturgeon in the region survive each year (Tavakoli et al. 2018, p. 381).

Overall, there is no indication that the species' decline has ended in its historical stronghold, the northern Caspian (or in other regions); poaching is continuing (Ermolin and Svolkinas 2018, pp. 3–13; Harris and Shiraishi 2018, p. 33) and we are not aware that any major dams have been decommissioned. Illegal fishing is expected to eliminate the remaining wild reproduction soon, leaving artificial stocking and aquaculture as the only (imperfect) hope for avoiding the species' extirpation from the Caspian basin (Gessner et al. 2010a; Reinartz and Slavcheva 2016, pp. 44–45).

Black and Azov basins

In the Black Sea basin, the outlook for Russian sturgeon is similarly bleak. The species is extirpated, or nearly so, from most of its former range in these basins because dams block access to upstream portions of most rivers (WSCS and WWF 2018, pp. 10–12 & Fig. 3). The species is gone from the Southern Bug, Dniester, Kızılırmak, and Sakarya Rivers (WSCS and WWF 2018, pp. 10–12 & pp. 30–31; Gessner et al. 2010a, not paginated). In the Black Sea itself, Russian sturgeon are now very rare (Gessner et al. 2010a, not paginated) and the species only remains in the Dnieper River because it is stocked with farmed fish (WSCS and WWF 2018, pp. 10–12).

Russian sturgeon may still reproduce naturally in the lower Danube River, but only infrequently and possibly not since 2010 (Reinartz et al. 2020e, p. 6; WSCS and WWF 2018, pp. 10–12 & pp. 30–31). The only suitable Danube spawning sites remaining are downstream of the Iron Gates II Dam (WSCS and WWF 2018, p. 30 & Table 2) which sits along the Romania-Serbia border, about 15 km upstream of Bulgaria and 600 km from the mouth of the Danube at the Black Sea. This is well over 1000 km river length from the species' former western extent in the Danube, near Regenburg, Germany (Gessner et al. 2010a, not paginated). Annual surveys along a small stretch of the Romanian Danube did not find any young-of-the-year between 2011 and 2020 (Reinartz et al. 2020a, p. 10).

The species may still reproduce in Georgia's Rioni river, but there is heavy fishing pressure there (WSCS and WWF 2018, p. 30 & Table 2; Reinartz and Slavcheva 2016, pp. 44–45). Any remaining population there is on the brink of extirpation (Fauna and Flora International 2019a, p. 2).

Russian sturgeon only persist in the Don and Kuban Rivers thanks to continuing release of farmed fish (WSCS and WWF 2018, pp. 10–12 & p. 31). There is no known natural reproduction there (WSCS and WWF 2018, pp. 10–12 & p. 31).

Ship sturgeon

Table 4.3—Current resiliency and redundancy of ship sturgeon.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency	Notes
Azov Sea					Nearly extirpated[1]
Don River	0[1]	1	1–2	Extirpated	Extirpated[2]
Kuban River	1[5]	1	1–2	3-5	Large restocking effort following extirpation[1, 5]
Black Sea					Nearly extirpated[1]
Danube	0[1, 4]	1	1	Extirpated	Last recorded in 2003 in Serbia at Apatin, 2005 in Mura in Hungary; both males[1]; no records in 10+ years as of 2018[2].
Dnieper	0[1, 2]	1	1–2	Extirpated	
Southern Bug	1[1]	1	1-3; unknown	3-5	Nearly extirpated[1]
Dniester	0[1, 2]	1	1–2	Extirpated	
Rioni	1–2[5]	1	1–2	3-5	Nearly extirpated; possibly breeding[5, 6]
Kızılırmak	0[1, 2]	1	2–3	Extirpated	
Sakarya	0[1, 2]	1	1–2	Extirpated	
Caspian Sea					
Volga	1[1, 7]	1	1	3	Rarely sighted[1]
Ural	2[1, 7]	2	2	6	Spawns[1]

Kura	1–2 [1, 8]	1–2	1–2	3-6	Small population might remain[8]
Terek	0[1, 7]	1–2	2–3	Extirpated	
Sefid-Rud	1[1, 7]	1	2–3	4-5	Present, no spawning[1]
Aral					Extirpated[3]
Syr-Darya	0[3]	1	1	Extirpated	
Amu-Darya	0[3]	1	1–2	Extirpated	
					
Redundancy score: 3.5. 7 extant populations, all in low or very low condition.					
References: [1]Gessner et al. 2010b, not paginated; [2]WSCS and WWF 2018, pp. 10–12 & pp. 35–36; [3]Lagutov & Lagutov 2008, pp. 194 & 252; [4]Friedrich et al. 2019, p. 1063; [5]Scheele 2020c, pers. comm.; [6]Fauna and Flora International 2020, p. 1; [7]Reinartz and Slavcheva 2016, p. 46; [8]Aladin et al. 2018, p. 2069. See Table 4.1 for connectivity and habitat quality citations.					

Ship sturgeon redundancy is low, with 7 or 8 of 16 focal rivers retaining the species, but all extant analysis units have low or very low resiliency. It is likely that no self-sustaining populations remain.

There is measurable genetic differentiation between ship sturgeon in the Ural River and southern Caspian (including Sefid-Rud) stocks of ship sturgeon (Qasemi et al. 2006, p. 164), but their representation is decreased by the extirpation of the fully freshwater Danube River population (WSCS and WWF 2018, p. 35; Billard and Lecointre 2001, p. 371). As for all Ponto-Caspian sturgeon, their representation may be further reduced where wild-born native fish breed with non-local fish used in restocking (WSCS and WWF 2018, p. 50) or with non-native sturgeon species escaped from aquaculture (Ludwig et al. 2009, p. 756).

Caspian basin

In the Caspian Basin, ship sturgeon still spawn in the Ural River, and are found rarely in the Volga (WSCS and WWF 2018, p. 36; Gessner et al. 2010b, not paginated). Only five ship sturgeon were caught in the Sefid-Rud River as long ago as 2002, and the species no longer breeds there (Gessner et al. 2010b, not paginated). The Kura likely has a remnant population, which may breed at low levels (Aladin et al. 2018, p. 2069), but the best information indicates the species is extirpated from the Terek River (Gessner et al. 2010b, not paginated).

Black and Azov basins

Ship sturgeon are now exceedingly rare throughout their range (Gessner et al. 2010b). As of 2018, the species had not been recorded in Daube River for over ten years (WSCS and WWF 2018, p. 35 & Table 2), and only 15 individuals were caught in the Danube between 1996 and 2001 (Gessner et al. 2010b, not paginated). The river does retain some suitable habitat for the species (Gessner et al. 2010b, not paginated), likely downstream of the Iron Gates II dam, but the species is considered extirpated there (Friedrich et al. 2019, p. 1063).

As of 2009, there had been no catch of the species in Ukraine—including the Southern Bug, Dniester, and Dnieper Rivers—for approximately 30 years (Gessner et al. 2010b, not paginated). When two small ship sturgeon were found in Georgia's Rioni River in March and April 2020, it

Figure 4.3—A young ship sturgeon found in the Rioni River, Georgia, in spring 2020 (Fauna and Flora International 2020, not paginated and Scheele, F., personal communications on March 26, 2020).

caused great excitement in the sturgeon conservation community; the species had not been seen there, either, for least several years (Scheele 2020a and 2020b, pers. comm.). The small size of the fish (Fig. 4.3) indicates likely recent reproduction, although genetic studies are underway to determine if they may have swam from the Kuban River where large reintroduction and restocking efforts are underway in Krasnodar, Russia (Scheele 2020c, personal comm.). Prior to this restocking effort, ship sturgeon were extirpated from the Kuban River and they remain so from the Azov's other main input, the Don, as well as Turkey's Kizilirmak and Sakarya Rivers (WSCS and WWF 2018, pp. 10–12).

Aral basin

The species is extirpated from the Aral Sea and both its major tributaries, the Amu-Darya and Syr-Darya (Aladin et al. 2018, p. 2077; Ermakhanov et al. 2012, p. 4, Gessner et al. 2010, not paginated). There is no hope for restoration until the water level of the Sea and the flow of the Syr-Darya and Amu-Darya are reestablished (Zholdasova 1997, p. 376). Dams block passage to their favored spawning grounds, 1800 km up the Syr-Darya River, as well as access to most spawning sites on the Amu-Darya (Zholdasova 1997, p. 374 and Fig. 1).

Persian sturgeon

Table 4.4—Current resiliency and redundancy of Persian sturgeon

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Caspian Sea				
Volga	0–2[1, 2]	1	1	2-4 (poss. extirpated)
Ural	0–2[1, 2]	2	2	2-6 (poss. extirpated)
Kura	1–2[1, 2]	1–2	1–2	3-6
Terek	0–2[1, 2]	1–2	2–3	3-7 (poss. extirpated)
Sefid-Rud	1–2[1, 2]	1	2–3	4-6

Very low Low Moderate High

4 7 10

Redundancy score: 1–3. 2–5 of 5 extant populations with 2 – 5 with low or very low resiliency and 0–1 with moderate resiliency.

References: [1]Gessner 2010c, not paginated; [2]Aladin 2018, p. 2069.
See Table 4.1 for Connectivity and Habitat quality citations.

The restricted historical range of Persian sturgeon limits its potential redundancy; only five focal rivers contained the species historically and as few as two may today. All extant populations have low or very low resiliency and it is likely that no self-sustaining populations remain. Relatively little is known about Persian sturgeon representation, but there does remain some level of genetic diversity in the species as the Sefid-Rud River population is genetically differentiated from the species in other southern Caspian locations (Khoshkholgh et al. 2013, pp. 33–34; Chakmehdouz Ghasemi et al. 2011, p. 602).

Persian sturgeon are most likely to remain breeding in the lower courses of the Sefid-Rud and Kura (Aladin et al. 2018, p. 2069). Reproduction is less likely in the Volga, Ural, and Terek (Gessner et al. 2010c, not paginated). There has been a steady decline in the proportion of females and their longevity for Persian and Russian sturgeon (Fig. 4.2; the authors of the data source do not differentiate the two taxa Fig. 4.2). Any ongoing breeding is of low volume.

Around 80% of Persian sturgeon caught by the still legal Iranian fishery were believed to be stocked individuals as of 2010 (Gessner 2010c, not paginated). In the absence of new and effective conservation measures, continuing fishing pressure to satisfy the international caviar market is expected to wipe out wild populations (Reinartz and Slavcheva 2016, p. 46; Gessner et al. 2010b, not paginated). The Allee effect, negative impacts on population persistence due to low population density and difficulty of finding mates, is a noted possibility for this species (Gessner et al. 2010b, not paginated).

Stellate sturgeon

Table 4.5—Current resiliency and redundancy of stellate sturgeon

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency	Notes
Azov Sea					
Don River	0[4]	1	1–2	Extirpated	No records for 10+ years as of 2018[4]
Kuban River	2[4]	1	1–2	4-5	Reproducing, with farmed releases[4]
Black Sea					
Danube	2[4, 6]	1	1	4	"Heavily overfished" [6]
Dnieper	0[4]	1	1–2	Extirpated	No records for 10+ years as of 2018[4]
Southern Bug	0[4]	1	1-3; unknown	Extirpated	Abundance unknown, but no indication it is self-sustaining
Dniester	0[4]	1	1–2	Extirpated	No records for 10+ years as of 2018[4]
Rioni	2[4,5]	1	1–2	4-5	Reproducing[4, 5]
Kızılırmak	0[4]	1	2–3	Extirpated	Extirpated[4]
Sakarya	2[4]	1	1–2	4-5	Reproducing[4]
Caspian Sea					
Volga	2[6, 7]	1	1	4	"Almost all migrating females are poached" [6]
Ural	2[6]	2	2	6	

Kura	2[1–3]	1–2	1–2	4-6	
Terek	1–2[2, 3]	1–2	2–3	4-7	
Sefid-Rud	2[1]	1	2–3	5-6	
Aegean Sea					
Marmara Sea, Evros River	0[3, 4]	1	1–2	Extirpated	

Redundancy score: 4.5–5. 9 extant populations, with 8–9 with low or very low resiliency and 0 – 1 with moderate resiliency.

References: [1]Norouzi and Pourkazemi 2015, p. 95; [2]Khodorevskaya 1997 cited in Ruban and Khodorevskaya 2011, p. 202; [3]Suciu and Qiwei 2010, not paginated; [4]WSCS and WWF 2018, pp. 10–12 & pp. 41–42; [5]Scheele 2020c, pers. comm.; [6]Reinartz and Slavcheva 2016, p. 48; [7]Khodorevskaya and Kalmykov 2014, p. 579
See Table 4.1 for Connectivity and Habitat quality citations.

Stellate sturgeon redundancy is low-to-moderate. At least 10 of 15 focal rivers retain the species, however all but one extant population are certain to have low or very low resiliency. Only the Terek River population may reach the low end of moderate resiliency. It is likely that no self-sustaining populations remain.

Representation appears moderate-to-high, but with substantial uncertainty. The diversity of haplotypes (specific sets of genes inherited from a single parental genome) from samples across the Caspian indicated considerable genetic diversity in the species (Doukakis et al. 2005, pp. 458–459). The Volga, Ural, and Sefid-Rud Rivers all had genetically distinct populations (Norouzi & Pourkazemi 2015 p. 98–99). However, at least a small number of stellate sturgeon in the Volga now hybridize with sterlet (Sergeev 2019, not paginated). Genetic diversity of lower Danube River stellate sturgeon did not decline between 1998 and 2010 (Holostenco 2011, p. 37) and there were an average of 8 different alleles (sequence variants) at sampled microsatellites (short repeating regions of DNA; Dudu et al. 2008, pp. 80–81).

The apparently high genetic variation within the species may be a relict of Black Sea-Caspian Sea connectivity and/or an artifact of artificial gene flow introduced by large-scale restocking programs using fish sourced from the Caspian Sea (Doukakis et al. 2005; p. 459). Indeed, translocation of fertilized eggs from the Caspian Sea to the Azov Sea diluted the local stellate sturgeon gene pool in the 1990s and early 2000s (Suciu and Qiwei 2010, not paginated).

Caspian basin

It is now rare for stellate sturgeon to breed in the Volga River, and most of those that do migrate up this river are harvested (Reinartz and Slavcheva 2016, p. 48). As of 1997, 60% of historical spawning grounds for the species were still available below the Volgograd Dam on the Volga River (Khodorevskaya et al. 1997, p. 213), but annual recruitment of stellate sturgeon juveniles into the commercial fishery from the Volga spawning grounds fell by over 97% between 1966 and 2011 (Khodorevskaya and Kalmykov 2014, p. 579). Most females that do live to spawn only do so once; the average age of female spawners in the Volga River is now less than half what it was 30 years ago (Ruban et al. 2019, p. 392). Only about 10% of stellate sturgeon spawning in the Volga were female as of 2012 (Ruban et al. 2019, p. 392). Spawning is also very uncommon in the Ural River now (Reinartz and Slavcheva 2016, p. 48).

A small population remains and breeds in the Sefid-Rud and the Kura River likely has a small population of spawning stellate sturgeon, although reproduction rates are very low and supplemented by restocking efforts (Norouzi and Pourkazemi 2015, pp. 95). Few recent data exist for the Terek River population, but it was said to be very small even in 1997 and there is no expectation that its situation has improved (Ruban and Khodorevskaya 2011, p. 202).

No records of stellate sturgeon are available for at least ten years from each of the Dnieper, Dniester, Southern Bug, and Kızılırmak Rivers (WSCS and WWF 2018, pp. 10–12 & pp. 41–42).

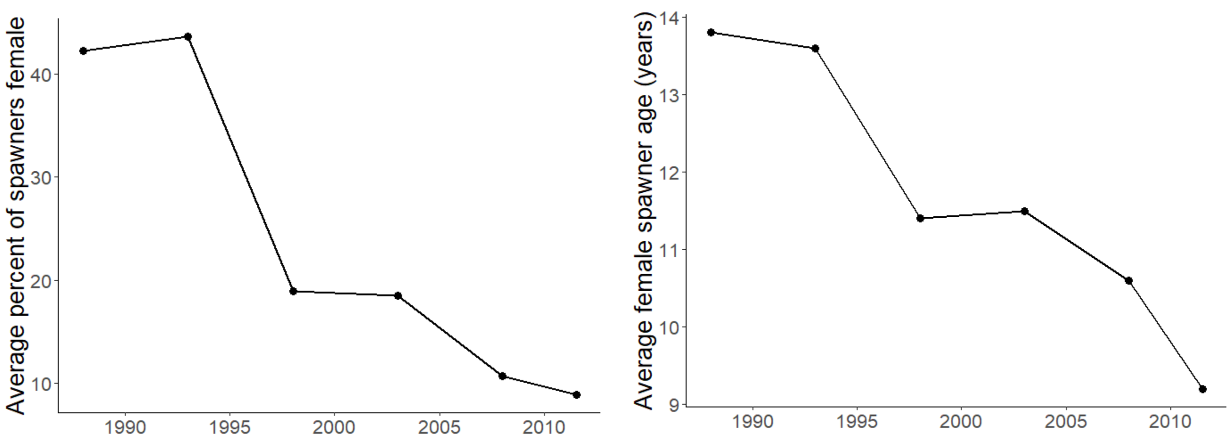


Figure 4.4—The average percent of stellate sturgeon spawners that were females (left) and the average age of those females (right) in the Volga River. Data from Ruban et al. 2019, p. 392. No measure of uncertainty within sampling time points was given.

Black, Azov, and Marmara basins

In the Black Sea basin, stellate sturgeon now migrate into and breed in very few rivers. In the Danube, the species reproduces but is still heavily poached and subject to mortality as bycatch (Reinartz and Slavcheva 2016, p. 48). Indeed, stellate sturgeon were largely depleted in the Danube by the mid-1990s (Bacalbasa-Dobrovici 1997, p. 201–203) and reproduction is minimal in most years (Reinartz et al. 2020e, p. 5). Annual surveys of a small stretch of river in the lower Danube since 2020 indicate new offspring are present most years, but do not show a clear trend towards recovery (Reinartz et al. 2020a, p. 2 and Fig. 7).

Ongoing reproduction was confirmed from the Rioni River in Georgia and the Sakarya River in Turkey in 2018 (WSCS and WWF 2018, p. 41) and stellate sturgeon also still reproduce in the Azov basin's Kuban River, where the population is aided by release of farmed stock (WSCS and WWF 2018, pp. 10–12). There is no indication that the remaining level of reproduction is sufficient to sustain any of these populations in light of ongoing threats.

Stellate sturgeon are extirpated from the Don River (WSCS and WWF 2018, pp. 10–12 & pp. 41–42), the Sea of Marmara at the northern extent of the Aegean Sea, and from the Struma and Evros Rivers that enter the Aegean as they flow through Bulgaria and Greece (WSCS and WWF 2018, p. 41).

Chapter 5—Forecasting the future condition of the species

In the final step of the SSA analysis, we forecast the future condition of the species under multiple alternative future scenarios (Smith et al. 2018, entire). These scenarios are built to represent plausible conditions given the range of potential threats and conservation the species may experience. The scenarios are not intended to encompass all possible outcomes and none should be construed as a prescription for conservation activities. Rather, they are designed to project future viability of the species under different plausible conditions.

Based on our assessment, we conclude that fishing pressure and its regulation, dams, invasive species, pollution, and restocking, all have considerable potential to affect the future viability of Ponto-Caspian sturgeon. We judged these threats to be more severe, and in some cases more imminent, than other threats and conservation measures detailed in Chapter 3 (water level changes, climate change, disease, and gene banking). We therefore built the range of scenarios assessed in consideration of the most relevant associated threats and conservation measures.

We are aware of two studies that project the impacts of illegal fishing in the Caspian basin and pollution in the Black and Azov basins to approximately the year 2050 (Strokal and Kroeze 2013, entire; Ye and Valbo-Jørgensen 2012, entire). Such forecasts of Ponto-Caspian sturgeon habitat and population viability are rare and subject to considerable uncertainty, but still provide some utility for our projections. In part due to the utility of these studies, we chose to forecast the viability of Ponto-Caspian sturgeon for 30 years from the present (2020–2050).

Moreover, the most important uncertainties in the future of Ponto-Caspian sturgeon are due human factors such as, politics, economics, pollution, and cultural preferences. For instance, local and international caviar markets depend on demand for this good, and desire for wild-sourced (as opposed to farmed) caviar remains high, at least for some consumers (Harris and Shiraishi 2018, p. 10). In the absence of additional regulatory measures, it is at least likely that the caviar market will be robust in the next few decades; indeed, a new and large middle class consumer market is emerging as farmed caviar becomes more affordable (Sicuro 2019, entire; Bronzi and Rosenthal 2014, p. 1545). Beyond that time period, it is harder to know how cultural shifts and awareness of sturgeon endangerment may affect demand.

For each of the three scenarios described below, we made qualitative projections of resiliency, redundancy, and representation for each of the four Ponto-Caspian sturgeon. These projections are based on published information and expert input regarding the species' current status, biology, and expected response to stressors and management actions. Throughout, we aim to illustrate the level of uncertainty that exists by assigning ranges of projected resiliency scores.

Scenario 1 is a *status quo* scenario simulating the effects of continuing the current threats and conservation measures. Scenario 2 considers the impacts of widespread implementation of conservation measures recommended by sturgeon experts. It represents broad adoption of multiple sturgeon-conservation activities. Scenario 3 is focused on the potential for improved mitigation of connectivity impacts, if effective passage structures can be engineered into existing dams. This is a more narrow conservation strategy than that included in Scenario 2.

Scenario 1: Continuation of current trajectory

The first scenario is for the case in which threats (overfishing, dams, invasive species, and pollution) and conservation activities (primarily restocking) continue to develop on their current trajectory. This means:

- Little-to-no legal commercial fishing throughout the Ponto-Caspian sturgeons' ranges;
- Continued bycatch of sturgeon, especially in the southern Caspian;
- Continued illegal harvest of sturgeon through most of their extant range, including in the Volga, Ural, and Danube;
- Limited effectiveness of restocking due to high mortality of young fish, the use of locally maladapted stocks, and harvest of stocked fish before their reproductive potential is realized;
- Construction of some additional dams (e.g., 31 proposed dams are currently under review in Iran's Caspian basin and 100 dams are already being built nationwide in Iran; Tehran Times 2020, not paginated) with few if any major dams removed;
- Moderate depletion of sturgeon prey in the Caspian basin (especially its southern reaches) due to invasive *Mnemiopsis* with annual short-term impacts of *Mnemiopsis* on Black and Azov Sea sturgeon prey base;
- Water quality may deteriorate in the Kizilirmak and Sakarya River basins as the human population in the region grows quickly (Strokal and Kroeze 2013, pp. 186–187);
- The Aral Sea basin will remain in nearly uninhabitable condition due to massive water withdrawals, high salinity, pollution, and dams, although the Amu-Darya River may continue to see limited improvement in water quality (Zholdasova 1997, p. 375).

The overwhelming consensus from experts is that current and historical conservation measures are not sufficient to allow viable populations of any of the four Ponto-Caspian sturgeon taxa. One wrote in 2006, "If illegal catch and deterioration of the Caspian Sea continues at the same pace as presently experienced, we will soon witness the extinction of sturgeon stocks in the Caspian Sea" (Pourkazemi 2006, p. 16). The recent Pan-European Action Plan for Sturgeons states "The conservation status of all sturgeon species in Europe has become highly critical without showing signs of recovery, indicating that previous action has not been successful" (WSCS and WWF 2018, p. 6). The Action Plan also details the lack of resources, accountability, and organization that has plagued sturgeon conservation in the region. A 2017 Danube Sturgeon Task Force report said that "the conservation status of sturgeon populations continued to worsen" as of 2010, despite a laundry list of ongoing conservation efforts (Sandu 2017, pp. 2–7). From these statements, it can only be expected that the condition of the Ponto-Caspian sturgeon will decline in most or all of their extant range under a *status quo* future.

Population modeling of the Caspian Sea stellate sturgeon stock indicates extirpation is likely by 2040 if illegal fishing continues at 2008 levels (Ye and Valbo-Jørgensen 2012, p. 27). It must be noted though that the conclusions of this study are subject to large uncertainty because the models are parameterized with very limited data. In particular, large uncertainty in the survival rate of individuals released in restocking efforts and for the current abundance and age class structure of stellate sturgeon is carried through to modeled viability. Restocking is also not considered in a consistent manner across models (Ye and Valbo-Jørgensen 2012, p. 27). Nonetheless, a clear and likely robust result is that the magnitude of the negative impact of continued illegal fishing is much greater than the benefits of current restocking programs (Ye and Valbo-Jørgensen 2012, p. 27).

The importance of controlling illegal harvest is echoed by other experts who call for intensive *in situ* anti-poaching efforts to be prioritized over *ex-situ* and restocking programs, where possible (WSCS and WWF 2017, p. 2). In light of the consensus that the *status quo* is not sufficient to achieve the decreased harvest needed for viable populations, we project a one-point decrease in resiliency for the reproductive success and abundance criterion for all analysis units, except where the score was already at the minimum (0), indicating current extirpation. Given the strong consensus that current management is insufficient to have viable populations, we consider this a conservative projection (i.e., on the lower end or mid-range of severity of declines that might occur) for the year 2050.

Although necessarily a broad-brush approach given the difficulty of making spatially explicit projections, a range-wide one-point decrease means different things for different populations. For example, in a population whose current reproductive success and abundance score is one, a decline to zero indicates extirpation. For a population that is presently breeding but at least likely not to be self-sustaining (two points), the decrease would indicate continuing presence but an at least likely cessation of breeding (Table 2.4).

Most focal rivers presently have a score of 1 for connectivity and there is little expectation of any consequential improvements in river connectivity under a continuation of the current conservation trajectory (Scheele 2020d, pers. comm.). We therefore do not change the connectivity scores under this scenario. Even in the rare case where one or two dams are removed, the large focal rivers all have additional dams that will continue to impede migration (Figs. 3.1 & 3.2). Additional dams are being built in Iran's Caspian basin territory (Tehran Times 2020, not paginated), where the Sefid-Rud River already has a score of 1 for connectivity.

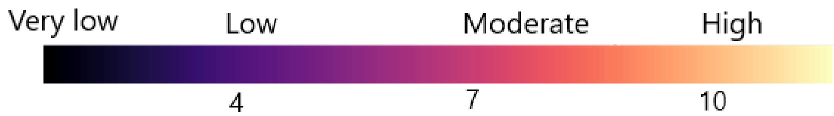
In general, we project habitat quality impacts due to *Mnemiopsis* to remain steady, somewhat worse in the Caspian than the Black and Azov Seas, but we do not have specific predictions of pollution trajectories for most rivers. Because of the uncertainty in habitat quality, we increased the range of scores for this criterion by 0.5 points above and below the current value in all analysis units, except where this was prevented by scores already at the minimum (one) or maximum (three). An increase of 0.5 points would indicate a lessening likelihood of pollution impacts to sturgeon health and prey availability; a corresponding decrease would mean the opposite (Tables 2.3 and 2.4). One exception was made for the Kizilirmak and Sakarya Rivers in Turkey, which are expected to become more polluted (Strokal and Kroeze 2013, p. 186–187). We lowered the habitat quality score of each of these rivers by one point relative to their current condition, unless it was already at one, the minimum score.

Russian sturgeon

Table 5.1—Projected resiliency and redundancy of Russian sturgeon under a *status quo* future.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0	1	1–2.5	**Extirpated**
Kuban River	0	1	1–3	**Extirpated**
Black Sea				
Danube	1	1	1–1.5	**3–3.5**
Dnieper	0	1	1–2.5	**Extirpated**
Southern Bug	0	1	1-3; unknown	**Extirpated**
Dniester	0	1	1–2.5	**Extirpated**
Rioni	1	1	1–2.5	**3–4.5**
Kızılırmak	0	1	1–2	**Extirpated**

Sakarya	0	1	1	Extirpated
Caspian Sea				
Volga	1	1	1–1.5	3–3.5
Ural	1	2	1.5–2.5	4.5–5.5
Kura	0	1–2	1–2.5	Extirpated
Terek	0	1–2	1.5–3	Extirpated
Sefid-Rud	0–1	1	1.5–3	2.5 – 5 (poss. extirpated)



Redundancy score: 2–2.5. 4–5 extant populations, all with low or very low resiliency.

Compared to their current condition, under a *status quo* future, Russian sturgeon are projected to be in far worse condition. Only 4–5 populations are projected to remain extant, a sizeable decrease in redundancy from the present 10–12 extant populations. The species' projected extirpation from the Azov Basin would reduce its representation. All remaining units are projected to have low or very low resiliency, which indicates they would not be self-sustaining.

Ship sturgeon

Table 5.2—Projected resiliency and redundancy of ship sturgeon under a *status quo future.*

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0	1	1–2.5	Extirpated
Kuban River	0	1	1–3	Extirpated
Black Sea				
Danube	0	1	1–1.5	Extirpated
Dnieper	0	1	1–2.5	Extirpated
Southern Bug	0	1	1-3; unknown	Extirpated
Dniester	0	1	1–2.5	Extirpated
Rioni	0–1	1	1–2.5	Extirpated
Kızılırmak	0	1	1–2	Extirpated
Sakarya	0	1	1	Extirpated
Caspian Sea				
Volga	0	1	1–1.5	Extirpated
Ural	1	2	1.5–2.5	4.5–5.5
Kura	0	1–2	1–2.5	Extirpated
Terek	0	1–2	1.5–3	Extirpated
Sefid-Rud	0	1	1.5–3	Extirpated

Aral				
Syr-Darya	0	1	1–1.5	**Extirpated**
Amu-Darya	0	1	1–2.5	**Extirpated**

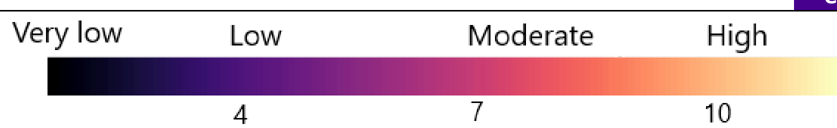
Redundancy score: 0.5. 1 extant population with low resiliency.

A *status quo* future would push ship sturgeon even closer to the brink of extinction, if not over the brink. Only one population out of 16 is projected to avoid extirpation and it is expected to have low resiliency. Because the species is projected to lose all extant populations in the Azov and Black Sea basins, representation and redundancy are projected to decline strongly under this scenario.

Persian sturgeon

Table 5.3—Projected resiliency and redundancy of Persian sturgeon under a *status quo future.*

	Reproductive success and abundance	Connectivity	Habitat quality	Total resiliency
Caspian Sea				
Volga	0–1	1	1–1.5	**2–3.5 (poss. extirpated)**
Ural	0–1	2	1.5–2.5	**3.5–5.5 (poss. extirpated)**
Kura	0–1	1–2	1–2.5	**2–5.5 (poss. extirpated)**
Terek	0–1	1–2	1.5–3	**2.5–6 (poss. extirpated)**
Sefid-Rud	0–1	1	1.5–3	**2.5–5 (poss. extirpated)**



Redundancy score: 0–2.5. 0–5 extant populations, all with low or very low resiliency.

The viability of Persian sturgeon would be severely tested under a *status quo* future. Because the species is a Caspian endemic with few populations to begin with, losing any of the at-most five currently extant populations is a serious hit to the species' redundancy. All units have the potential to be extirpated and are otherwise projected to have low-to-very low resiliency.

Stellate sturgeon

Table 5.4—Projected resiliency and redundancy of stellate sturgeon under a *status quo future.*

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency

Azov Sea				
Don River	0	1	1–2.5	**Extirpated**
Kuban River	1	1	1–3	**3–5**
Black Sea				
Danube	1	1	1–1.5	**3–4.5**
Dnieper	0	1	1–2.5	**Extirpated**
Southern Bug	0	1	1-3; unknown	**Extirpated**
Dniester	0	1	1–2.5	**Extirpated**
Rioni	1	1	1–2.5	**3–4.5**
Kızılırmak	0	1	1–2	**Extirpated**
Sakarya	1	1	1	**3**
Caspian Sea				
Volga	1	1	1–1.5	**3–4.5**
Ural	1	2	1.5–2.5	**4.5–5.5**
Kura	1	1–2	1–2.5	**3–5.5**
Terek	0–1	1–2	1.5–3	**2.5–6 (poss. extirpated)**
Sefid-Rud	1	1	1.5–3	**3.5–5**
Aegean Sea				
Marmara Sea, Evros River	0	1	1–2.5	**Extirpated**

Redundancy score: 4–4.5. 8–9 extant populations, all with low or very low resiliency.

One additional population of stellate sturgeon may be extirpated under Scenario 1. Although fairly few extirpations are projected, the projected reproductive success and abundance scores indicate most are on the precipice of disappearance under this scenario and the species' redundancy score is projected to decline by up to 20% (4 from 5). The species is not projected to be extirpated from any full basins beyond its current absence from the Aegean Sea and Evros River. Therefore, representation should be relatively similar to its presently high level, although only one very low resiliency population is projected to remain in the Azov basin.

Scenario 2: Proactive conservation

In the second future scenario, we describe the likely effect on Ponto-Caspian sturgeon of instituting considerably more aggressive conservation efforts. Even though these are not currently being implemented in any comprehensive way and are under-funded and lack broad government support, the specific measures that we consider part of such a proactive conservation scenario are those described in recent expert reports and action plans for the Ponto-Caspian region (WSCS and WWF 2018, pp. 13–14 & 52–60; WSCS and WWF 2017, entire; Reinartz and Slavcheva 2016, p. 77). These include:

- Strict protection of remaining sturgeon spawning grounds from hydrological engineering including dams, water withdrawal, sand and gravel mining, and pollution;
- Improved enforcement of fishing bans and prosecution of sturgeon poachers leading to a sizeable decrease in illegal fishing;

- Significant reduction in by-catch of sturgeon in the southern Caspian and throughout the Black Sea;
- Widespread adoption and standardization of CITES-recommended caviar labeling schemes to clearly identify legal versus illegal and farmed- versus wild-sourced sturgeon products in both domestic and international trade;
- Better-informed restocking programs that use only locally adapted stocks of native species and that use documented, scientifically informed programs to manage stock genetic diversity;
- At least partial restoration of Aral Sea water levels and quality;
- Where necessary, development of economic aid programs that present small human communities reliant on sturgeon fishing with alternative livelihood opportunities.

The models of Caspian Sea stellate sturgeon populations mentioned in the Scenario 1 discussion indicate the fish's population would rebound by 2050, if illegal fishing is stopped, although there is high uncertainty in the degree of recovery (Ye and Valbo-Jørgensen 2012, p. 25). Total abundance is forecast to approach the levels last seen between 1960 and 1980 (Ye and Valbo-Jørgensen 2012, p. 25), just before the most catastrophic crash in fisheries yield (Figs. 3.6 & 3.7) and population size. It is very likely this outcome would extend to the Black and Azov Seas, and to Russian, ship, and Persian sturgeon, too, given the similar threats they face and their similar life history strategies. Improving restocking practices beyond their current level can be expected to yield an additional but considerably smaller boost to Ponto-Caspian sturgeon viability (Ye and Valbo-Jørgensen 2012, p. 25).

More effective law enforcement and the provision of alternative livelihoods can be achieved if governments value sturgeon conservation and non-governmental organizations are funded to assist in these efforts. An example of such efforts is the ongoing Flora and Fauna International sturgeon conservation program (funded in part by the Service) in the Rioni River basin in Georgia. Rangers are employed to monitor and report poaching incidents in collaboration with local law enforcement. This provides jobs tied to sturgeon well-being and helps advance awareness of sturgeon conservation (Fauna and Flora International 2019b, p. 4).

Standardization of CITES-compliant caviar labels will help close loopholes that make forging these labels easier (WSCS and WWF 2017, p. 11). This would likely reduce the volume of illegally sourced sturgeon products that are laundered into the legal trade (WSCS & WWF 2017, p. 11) in Russia and to a lesser extent internationally (Gessner, Ludwig, and Congiu, 2020 pers. comm.). It would also facilitate enforcement across the European Union, which largely employs CITES-approved labels for domestic caviar trade, but without standardization of their format.

For populations that are presently extirpated, we did not assume they would necessarily be revived because that depends on the eventual selection of restocking sites. Therefore, we retained 0 as the low-end bound on all such units' reproductive success and abundance scores. As in Scenario 1, we increased the level of uncertainty in habitat quality by 0.5 points for each unit because it is unclear what the future holds in this respect for most rivers in the region (Kizilirmak and Sakarya excepted again). We did not alter connectivity scores from their current level because it is unlikely that major dams blocking migration routes would be removed (Scheele 2020d, pers. comm.; WSCS and WWF 2018, pp. 13–14 & 52–60; WSCS and WWF 2017, entire; Reinartz and Slavcheva 2016, p. 77).

To account for the uncertainty inherent in qualitative projections produced from a range-wide understanding of the likely impacts of investment in Ponto-Caspian sturgeon conservation, we assigned an increase of two-to-four points to each population's reproductive success and abundance score. This level of improvement is indicative of the expected potential improvements due to reduced fishing and bycatch (both legal and illegal), improved water quality, and better administration of both restocking programs and CITES-recommended labeling. These improvements would better provide clean water, abundant prey, and the ability to survive to reproduce multiple times. Four-point improvement in reproductive success and abundance is a major change and signals a population is at least more likely than not to be self-sustaining (Table 2.4). With a more conservative two-point increase, populations that are currently extirpated or at least likely not to be breeding would still have no better than an even chance of being self-sustaining (Table 2.4).

Russian sturgeon

Table 5.5—Projected resiliency and redundancy of Russian sturgeon under a proactive conservation future.

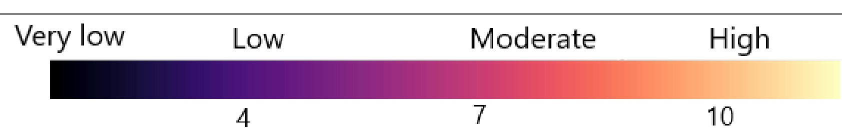
	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0–4	1	1–2.5	2–7.5 (poss. extirpated)
Kuban River	0–5	1	1–3	2–9 (poss. extirpated)
Black Sea				
Danube	4–6	1	1–1.5	6–8.5
Dnieper	3–5	1	1–2.5	5–8.5
Southern Bug	3–5	1	1-3; unknown	5–8
Dniester	4–6	1	1–2.5	6–9.5
Rioni	4–6	1	1–2.5	6–9.5
Kızılırmak	0–4	1	1–2	2–7 (poss. extirpated)
Sakarya	3–5	1	1	5–7
Caspian Sea				
Volga	4–6	1	1–1.5	6–8.5
Ural	4–6	2	1.5–2.5	7.5–10.5
Kura	3–5	1–2	1–2.5	5–9.5
Terek	3–5	1–2	1.5–3	5.5–10
Sefid-Rud	3–6	1	1.5–3	5.5–10
Very low	Low	Moderate	High	
	4	7	10	
Redundancy score: 6–14. 11–14 extant populations, with 0–13 with low or very low resiliency and 1–14 with moderate resiliency.				

Up to three Russian sturgeon populations could be restored from their current extirpated state and there is the possibility for many populations to have moderate resiliency. As such, redundancy is projected to improve considerably in this scenario, although the degree of improvement depends on the uncertainty in resilience, which is primarily due to the range of possible scores for both the spawning success and abundance and habitat quality criteria.

Ship sturgeon

Table 5.6—Projected resiliency and redundancy of ship sturgeon under a proactive conservation future.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0–5	1	1–2.5	2–8.5 (possibly extirpated)
Kuban River	3–5	1	1–3	5–9
Black Sea				
Danube	0–4	1	1–1.5	2–6.5 (poss. extirpated)
Dnieper	0–4	1	1–2.5	2–7.5 (poss. extirpated)
Southern Bug	3–5	1	1-3; unknown	5–9
Dniester	0–4	1	1–2.5	2–7.5 (poss. extirpated)
Rioni	3–5	1	1–2.5	5–8.5
Kızılırmak	0–4	1	1–2	2–7 (poss. extirpated)
Sakarya	0–4	1	1	3–6 (poss. extirpated)
Caspian Sea				
Volga	3–5	1	1–1.5	5–7.5
Ural	4–6	2	1.5–2.5	7.5–10.5
Kura	3–6	1–2	1–2.5	5–10.5
Terek	0–4	1–2	1.5–3	2.5–8 (poss. extirpated)
Sefid-Rud	3–5	1	1.5–3	5.5–9
Aral				
Syr-Darya	0–4	1	1–1.5	2–6.5 (poss. extirpated)
Amu-Darya	0–4	1	1–2.5	2–6.5 (poss. extirpated)



Redundancy score: 4–14. 7–16 extant populations, with 0–15 with low or very low resiliency and 1–15 with moderate or high resiliency.

Up to nine ship sturgeon populations are projected to be restored from extirpation to low or moderate condition in this scenario. The least likely to be restored are those in the Aral Sea rivers, but even these could be of low resiliency under an optimistic outcome. The upper bound on ship sturgeon redundancy is correspondingly projected to increase from its current level, with the degree of improvement dependent on where within the range of resiliency uncertainty each population ends up. The species is projected to be in slightly better condition in the Caspian basin than in the Black, Azov, and Aral basins. Representation of the species could increase if the Amu-Darya and Syr-Darya populations in the Aral basin are indeed revived.

Persian sturgeon

Table 5.7—Projected resiliency and redundancy of Persian sturgeon under a proactive conservation future.

	Reproductive success and abundance	Connectivity	Habitat quality	Total resiliency
Caspian Sea				
Volga	0–6	1	1–1.5	**2–8.5 (poss. extirpated)**
Ural	0–6	2	1.5–2.5	**3.5–10.5 (poss. extirpated)**
Kura	3–6	1–2	1–2.5	**5–10.5**
Terek	0–6	1–2	1.5–3	**2.5–10 (poss. extirpated)**
Sefid-Rud	3–6	1	1.5–3	**5.5–10**
Very low	Low (4)	Moderate (7)	High (10)	
Redundancy score: 1–5. 2–5 extant populations, with 0–5 with low or very low resiliency and 0–5 with moderate or high resiliency.				

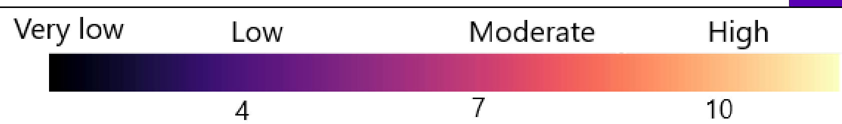
The lower-bound redundancy score for Persian sturgeon in this scenario is the same as at present (one extant population with low resiliency) but the upper bound is higher. There is the potential for all five populations to have moderate resiliency and two (in the Ural and Kura Rivers) could even reach the low end of high resiliency. Representation is unlikely to change greatly given that the species only inhabits one basin and thirty years is a short time for genetic diversity to accrue.

Stellate sturgeon

Table 5.8—Projected resiliency and redundancy of stellate sturgeon under a proactive conservation future.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0–4	1	1–2.5	**2–7.5 (poss. extirpated)**
Kuban River	4–6	1	1–3	**6–10**
Black Sea				

Danube	4–6	1	1–1.5	6–8.5
Dnieper	0–4	1	1–2.5	2–7.5 (poss. extirpated)
Southern Bug	0–4	1	1-3; unknown	2–9 (poss. extirpated)
Dniester	0–4	1	1–2.5	2–4.5 (poss. extirpated)
Rioni	4–6	1	1–2.5	6–9.5
Kızılırmak	0–4	1	1–2	2–7 (poss. extirpated)
Sakarya	4–6	1	1	6–8
Caspian Sea				
Volga	4–6	1	1–1.5	6–8.5
Ural	4–6	2	1.5–2.5	7.5–10.5
Kura	4–6	1–2	1–2.5	6–10.5
Terek	3–6	1–2	1.5–3	5.5–11
Sefid-Rud	4–6	1	1.5–3	6.5–10
Aegean Sea				
Marmara Sea, Evros River	0–4	1	1–2.5	2–7.5 (poss. extirpated)



Redundancy score: 5–14.5. 9–15 extant populations with 0–14 with low or very low resiliency and 1–14 with moderate or high resiliency.

The upper bound of redundancy is much improved for stellate sturgeon in this scenario compared to at present. This is because up to six populations would be restored from extirpation and resiliency could increase, too. There is potential for all 14 populations to have moderate resiliency and up to five could have high resiliency. Still, there is large uncertainty and it is possible for all populations to have low or very low resiliency. Representation could be slightly improved if the one Marmara Sea population is restored to the Evros River.

Scenario 3: Dam mitigation

The third scenario considers the possibility of widespread installation of measures to mitigate the loss of connectivity caused by dams, along with a stoppage of new dam construction, across the Ponto-Caspian region. It may become possible to retrofit dams with passage structures that effectively allow migration. Both adults and recent offspring would need to move through or around dams safely, upstream and downstream, to migrate to and from spawning grounds (Cooke et al. 2020, entire; WSCS and WWF 2017, p. 5; Reinartz and Slavcheva 2016, p. 77).

That said, retrofitting of existing dams with engineering to allow fish passage is difficult for sturgeon, given the large size of adults, the small, delicate nature of juveniles, and the massive, powerful turbines that must be traversed when travelling downstream through large hydroelectric dams (Cooke et al. 2020, entire; Billard and Lecointre 2001, p. 380). To date, there are few examples of successful passage structures for sturgeon and nearly all documented efforts have focused on North American species and rivers (Cooke et al. 2020, p. 224). Even where sturgeon do manage to pass through a dam, they may become disoriented by the switch between slow-moving upstream reservoirs and faster-flowing downstream rivers (Cooke et al. 2020, p. 229). This combined with the lack of information on which dams already have passage structures (and whether they are maintained in a functional condition; Cooke et al. 2020, p. 224; Dickinson 2018; not paginated) means there is high uncertainty in the benefits available to sturgeon from dam passageways.

Still, there are ongoing studies to design more successful passage technologies, including in the Danube River (International Commission for the Protection of the Danube River 2018, p. 9), and we consider it possible that research advances by 2050 will yield major improvements in passage engineering. Similar advances allow salmonid passage in many rivers although their biology eliminates some of the challenges faced in designing sturgeon passageways. In the interim and where fish cannot pass a dam, construction of side channels that allow at least 30% of natural river flow volume to pass at all times can have substantial benefits for habitat quality by allowing travel of sediment and gravel to downstream spawning grounds (WSCS and WWF 2017, p. 5).

Because of the uncertain effectiveness of passage structures for sturgeon, we do not assign a definitive increase in connectivity to any analysis units in our projections for this scenario. Rather, we increase the upper range of connectivity scores by 1 point relative to the current condition connectivity scores. We assume that any major advances in sturgeon passageway technology would be deployed to all dams and so do not consider the number of dams on a river. The exception was where this would yield a score of 3 because we do not anticipate the removal of major dams, which would be necessary to fully restore connectivity.

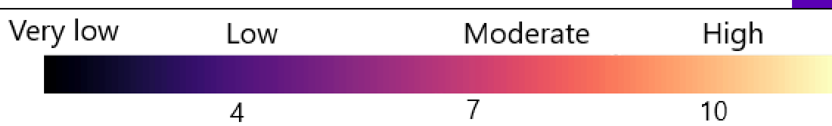
Because Scenario 3 is the same as Scenario 1 with the addition of somewhat improved connectivity, we scored reproductive success and abundance by beginning with the final scores from Scenario 1 and allowing an additional point on the upper end of score ranges, except for currently extirpated populations. This accounts for the potential increase in population size where improved connectivity allows access to currently inaccessible spawning grounds. We do not assign a definitive improvement in this criterion because we do not have data on exactly how much spawning area would be made accessible with passage allowed at each dam or river. We used the same habitat quality scores as in Scenario 1 because the same uncertainty exists in whether there might be slight improvements or declines in water quality and *Mnemiopsis* impacts.

Russian sturgeon

Table 5.9—Projected resiliency and redundancy of Russian sturgeon under a future with mitigation of dam impacts.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0–1	1–2	1–2.5	**2–4.5 (poss. extirpated)**
Kuban River	0–1	1–2	1–3	**2–6 (poss. extirpated)**

Black Sea				
Danube	1–2	1–2	1–1.5	**3–5.5**
Dnieper	0–1	1–2	1–2.5	**2 –5.5 (poss. extirpated)**
Southern Bug	0–1	1–2	1-3; unknown	**2–6 (poss. extirpated)**
Dniester	0	1–2	1–2.5	**Extirpated**
Rioni	1–2	1–2	1–2.5	**3–6.5**
Kızılırmak	0	1–2	1–2	**Extirpated**
Sakarya	0–1	1–2	1	**2–4 (poss. extirpated)**
Caspian Sea				
Volga	1–2	1–2	1–1.5	**3–5.5**
Ural	1–2	2	1.5–2.5	**4.5–6.5**
Kura	0–1	1–2	1–2.5	**2–5.5 (poss. extirpated)**
Terek	0–1	1–2	1.5–3	**2.5–6 (poss. extirpated)**
Sefid-Rud	0–2	1–2	1.5–3	**2.5–7 (poss. extirpated)**



Redundancy score: **2–6.5.** 4–12 extant populations with 4–12 with low or very low resiliency and 0–1 with moderate resiliency.

Under a future with improved dam impact mitigation, the condition of Russian sturgeon is more likely than not to be intermediate between its present condition and that projected in Scenario 1, where no additional conservation measures are assumed. Several additional populations could become extirpated and most are more likely than not to see declining resiliency due to continuing fishing pressure, pollution, and lingering dam impacts, especially until such time as they are mitigated. However, if mitigation occurs early and successfully enough in the future, there is limited potential for small improvements in most extant populations' resiliency. Because connectivity is already moderate in the Ural River, we do not project an improvement in this river's connectivity score and this population is very likely to decrease in resiliency due to continuation of other threats.

Regardless, only one population (in the Sefid-Rud River) could reach even moderate resiliency. Redundancy is therefore likely to be lower than at present but higher than under Scenario 1. Representation could decrease if the species is extirpated from the Azov Sea basin.

Ship sturgeon

Table 5.10—Projected resiliency and redundancy of ship sturgeon under a future with mitigation of dam impacts.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				
Don River	0–1	1–2	1–2.5	Extirpated
Kuban River	0–1	1–2	1–3	2–6 (poss. extirpated)
Black Sea				
Danube	0	1–2	1–1.5	Extirpated
Dnieper	0	1–2	1–2.5	Extirpated
Southern Bug	0–1	1–2	1-3; unknown	2–6 (poss. extirpated)
Dniester	0	1–2	1–2.5	Extirpated
Rioni	0–2	1–2	1–2.5	2–6.5 (poss. extirpated)
Kızılırmak	0	1–2	1–2	Extirpated
Sakarya	0	1–2	1	Extirpated
Caspian Sea				
Volga	0–1	1–2	1–1.5	2–4.5 (poss. extirpated)
Ural	1–2	2	1.5–2.5	4.5–6.5
Kura	0–1	1–2	1–2.5	2–5.5 (poss. extirpated)
Terek	0	1–2	1.5–3	Extirpated
Sefid-Rud	0–1	1–2	1.5–3	2.5–6 (poss. extirpated)
Aral				
Syr-Darya	0	1–2	1–1.5	Extirpated
Amu-Darya	0	1–2	1–2.5	Extirpated

Very low Low Moderate High

4 7 10

Redundancy score: 0.5–3.5. 1–8 extant populations all with low or very low resiliency.

Under a future with improved mitigation of dam impacts, the condition of ship sturgeon is more likely than not to be intermediate between its present state and that projected in Scenario 1, where no additional conservation measures are assumed. Several additional populations could become extirpated due to continuing fishing pressure, pollution, and lingering dam impacts until such time as they are mitigated. However, if dam mitigation occurs early and successfully enough in the future, there is limited potential for small improvements in most extant populations' resiliency. Because connectivity is already moderate in the Ural River, we do not project an improvement in this river's connectivity score and the population is most likely to decrease in resiliency due to continuation of other threats.

Regardless, all extant populations are projected to have low or very low resiliency. Redundancy is likely to be lower than at present but higher than under Scenario 1. Representation could decrease if the species is extirpated from either or both of the Azov or Black Sea basins.

Persian sturgeon

Table 5.11—Projected resiliency and redundancy of Persian sturgeon under a future with mitigation of dam impacts.

	Reproductive success and abundance	Connectivity	Habitat quality	Total resiliency
Caspian Sea				
Volga	0–2	1–2	1–1.5	**2–5.5 (poss. extirpated)**
Ural	0–2	2	1.5–2.5	**3.5–6.5 (poss. extirpated)**
Kura	0–2	1–2	1–2.5	**2–6.5 (poss. extirpated)**
Terek	0–2	1–2	1.5–3	**2–7 (poss. extirpated)**
Sefid-Rud	0–2	1–2	1.5–3	**2–7 (poss. extirpated)**
Very low	Low	Moderate	High	
	4	7	10	
Redundancy score: 0–3.5. 0–5 extant populations with 0–5 with low or very low resiliency and 0–2 with moderate resiliency.				

The very limited distribution of Persian sturgeon means that its viability will be precarious under a future with improved mitigation of dam impacts, just as it would be in the other two scenarios. There is only very limited room for improved condition, given the continuing threats posed by fishing, pollution, and any dam impacts that remain, or that are not mitigated until late in the 30-year future. Two of the five populations could achieve moderate resiliency, but all are likely to have low or very low resiliency, or to be extirpated. The species could become extinct in the wild, although that is less than likely. Under Redundancy and representation would remain very low.

Stellate sturgeon

Table 5.12—Projected resiliency of stellate sturgeon under a future with mitigation of dam impacts.

	Reproductive success and abundance	Connectivity	Habitat quality	Total Resiliency
Azov Sea				

Don River	0	1–2	1.5–2.5	Extirpated
Kuban River	1–2	1–2	1.5–3	3.5–7
Black Sea				
Danube	1–2	1–2	1–1.5	3–5.5
Dnieper	0	1–2	1–2.5	Extirpated
Southern Bug	0	1–2	1-3; unknown	Extirpated
Dniester	0	1–2	1.5–2.5	Extirpated
Rioni	1–2	1–2	1–2.5	3–6.5
Kızılırmak	0	1–2	2	Extirpated
Sakarya	1–2	1–2	1	3–5
Caspian Sea				
Volga	1–2	1–2	1–1.5	3–5.5
Ural	1–2	2	1.5–2.5	4.5–6.5
Kura	1–2	1–2	1–2.5	3–6.5
Terek	0–2	1–2	1.5–3	2.5–7 (poss. extirpated)
Sefid-Rud	1–2	1–2	1.5–3	3.5–7
Aegean Sea				
Marmara Sea, Evros River	0	1–2	1–2.5	Extirpated
Very low / Low (4) / Moderate (7) / High (10)				
Redundancy score: 4–6. 8–9 extant populations with 6–9 with low or very low resiliency and 0–2 with moderate resiliency.				

Under a future with improved mitigation of dam impacts, the condition of stellate sturgeon is more likely than not to be intermediate between its present state and that projected in Scenario 1, where no additional conservation measures are assumed. As in Scenario 1, only the Terek River population could become extirpated due to continuing fishing pressure, pollution, and lingering dam impacts until such time as they are mitigated. If dam mitigation occurs early and successfully enough in the future, there is limited potential for small improvements in resiliency of most populations. Because connectivity is already moderate in the Ural River, we do not project an improvement in this river's connectivity score and the population is most likely to decrease in resiliency due to continuation of other threats.

Regardless, only two populations have the potential to reach even moderate resiliency, with all other extant populations having low or very low resiliency. Redundancy will not change much compared to the present. Although it could improve slightly, it would still be low because of the low resiliency of all or nearly all populations. Representation is projected to remain steady because there are not projected to be any basin-wide extirpations and 30 years is a relatively short time period for accrual of meaningful new genetic variation.

Summary of current and future condition

Russian sturgeon

That the viability of Russian sturgeon is presently at risk is clear from the low or very low resiliency of all extant populations across the sea basins it inhabits (Table 5.13). There is potential for improvement under an aggressive, well-funded, and coordinated set of pro-active conservation measures (Scenario 2), but a continuation of the *status quo* would push the species to the brink of global extinction in the wild by 2050; only four rivers are projected to definitively maintain extant populations under such a future (Scenario 1). If the blockage by dams of spawning and post-hatching migration between seas and spawning grounds is alleviated by future development and deployment of effective dam passage structures (Scenario 3), the declines projected for a *status quo* future could be somewhat reduced and fewer extirpations would be expected. Still, all or nearly all populations would have low or very low resiliency.

Table 5.13—Total resilience scores for Russian sturgeon at present (top row) and under the three future scenarios. Sea basins are ordered and colored from left to right including the Azov, Black, and Caspian.

	Don	Kuban	Danube	Dniper	Southern Bug	Dniester	Rioni	Kizilirmak	Sakarya	Volga	Ural	Kura	Terek	Sefid-Rud
Present	2-4*	2-4*	4	3-4	3-6	Extirpated	4-5	Extirpated	3-4	4	6	3-5	4-6	4-6
Status quo	Extirpated	Extirpated	3-3.5	Extirpated	Extirpated	Extirpated	3-4.5	Extirpated	Extirpated	3-3.5	4.5-5.5	Extirpated	Extirpated	2.5-5*
Proactive conservation	2-7.5*	2-9*	6-8.5	5-8.5	5-8	6-9.5	6-9.5	2-7*	5-7	6-8.5	7.5-10	5-9.5	5.5-10	5.5-10
Dam mitigation	2-4.5*	2-6*	3-5.5	2-5.5*	2-6*	Extirpated	3-6.5	Extirpated	2-4*	3-5.5	4-6.5	2-5.5*	2.5-6*	2.5-7*

Ship sturgeon

Ship sturgeon are extant in only seven focal rivers at present and all of these populations have low or very low resiliency (Table 5.14). Without major conservation investments (Scenario 2), it very likely this species' condition will continue to decline. If the current trajectory continues (*status quo,* Scenario 1; Table 5.14), only the Ural River population is projected to be extant by 2050. Even with mitigation of dam impacts, it is possible, although less likely, that this is the sole population that will avoid extirpation (Scenario 3). Pro-active conservation activities targeting the threats posed by fishing, pollution, and ineffective restocking practices could rehabilitate the species, although this would require significant, coordinated activities across the range (Scenario 2).

Table 5.14—Total resilience scores for ship sturgeon at present (top row) and under the three future scenarios. Sea basins are ordered and colored from left to right including the Azov, Black, Caspian, and Aral.

	Don	Kuban	Danube	Dniper	Southern Bug	Dniester	Rioni	Kizilirmak	Sakarya	Volga	Ural	Kura	Terek	Sefid-Rud	Syr-Darya	Amu-Darya
Present	Extirpated	3-5	Extirpated	Extirpated	3-5	Extirpated	3-5	Extirpated	Extirpated	3	6	3-6	Extirpated	4-5	Extirpated	Extirpated
Status quo	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	4.5-5.5	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
Proactive conservation	2.5-8.5*	5-9	2-6.5*	2-7.5*	5-9	2-7.5*	5-8.5	2-7*	3-6*	5-7.5	7.5-10.5	5-10.5	2.5-8*	5.5-9	2-6.5*	2-6.5*
Dam mitigation	Extirpated	2-6*	Extirpated	Extirpated	2-6*	Extirpated	2-6.5*	Extirpated	Extirpated	2-4.5*	4.5-6.5	2-5.5*	Extirpated	2.5-6*	Extirpated	Extirpated

Persian sturgeon

Because Persian sturgeon are limited geographically to the Caspian basin, the species has naturally low redundancy. At present, no more than five populations exist and up to three of these may be extirpated already (Table 5.15). Without a change in the trajectory of threats and conservation measures, there is a possibility of global extinction in the wild by 2050 (*status quo*, Scenario 1; Table 5.15). Broad improvement of conservation activities across the species' range could ensure that two-to-five populations remain extant, although this would require a significant investment of conservation and restoration resources compared to the present (Scenario 2). Mitigation of dam impacts to connectivity between spawning and feeding grounds could slightly blunt the declines projected under a *status quo* future, if effective dam passage structures are developed and installed early in the next decade or two.

Table 5.15—Total resilience scores for Persian sturgeon at present (top row) and under the three future scenarios.

	Volga	Ural	Kura	Terek	Sefid-Rud
Present	2-4*	2-6*	3-6	3-7*	4-6
Status quo	2-3.5*	3.5-5.5*	2-5.5*	2.5-6*	2.5-5*
Proactive conservation	2-8.5*	3.5-10.5*	5-10.5	2.5-10*	5.5-10
Dam mitigation	2-5.5*	3.5-6.5*	2-6.5*	2-7*	2-7*

Stellate sturgeon

There is presently no more than one stellate sturgeon population with at least moderate resiliency (Table 5.16). Without a change to the trajectory of threats and conservation measures, the Terek River population could become extirpated by 2050, which would leave only eight extant populations range-wide, all with low or very low resiliency (*status quo*, Scenario 1; Table 5.16). Mitigation of dam impacts, specifically, would increase the upper-bound on extant populations' resiliencies (Scenario 3), but even so, only three populations would have the potential to reach the low end of moderate resilience. With coordinated, aggressive implementation of new and improved conservation measures across the range, the species could recover considerably (Scenario 2). In this case, up to 15 populations could be extant and all could reach moderate resiliency, though it is also possible that only one would.

Table 5.16—Total resilience scores for stellate sturgeon at present (top row) and under the three future scenarios. Sea basins are ordered and colored from left to right including the Azov, Black, Caspian, and Marmara.

	Don	Kuban	Danube	Dniper	Southern Bug	Dniester	Rioni	Kizilirmak	Sakarya	Volga	Ural	Kura	Terek	Sefid-Rud	Marmara Sea, Evros River
Present	Extirpated	4-5	4	Extirpated	Extirpated	Extirpated	4-5	Extirpated	4-5	4	6	4-6	4-7	5-6	Extirpated
Status quo	Extirpated	3-5	3-4.5	Extirpated	Extirpated	Extirpated	3-4.5	Extirpated	3	3-4.5	4.5-5.5	3-5.5	2.5-6*	3.5-5	Extirpated
Proactive conservation	2-7.5*	6-10	6-8.5	2-7.5*	2-9*	2-4.5*	6-9.5	2-7*	6-8	6-8.5	7.5-10.5	6-10.5	5.5-11	6.5-10	2-7.5*
Dam mitigation	Extirpated	3.5-7	3-5.5	Extirpated	Extirpated	Extirpated	3-6.5	Extirpated	3-5	3-5.5	4.5-6.5	3-6.5	2.5-7*	3.5-7	Extirpated

Very low Low Moderate High

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Appendix I—Calibration of likelihood terminology.

Table A1.1—Calibration of likelihood terminology used in the report.

Likelihood Terminology	Likelihood of the occurrence/ outcome
Virtually certain	> 99% probability
Extremely likely	95–99% probability
Very likely	90–95% probability
Likely	75–89% probability
More likely than not	50–74% probability
As likely as not	About 50% probability
Unlikely	< 50% probability

Appendix II—Climate change analysis

We calculated the projected future change in mean annual air temperature and precipitation for the Black, Caspian, and Aral Sea basins (see *Climate change* in Chapter 3) from a set of climate models for the period 2041–2060. Basin areas were as delineated in the HydroBasins dataset (Lehner 2013, entire).

We downloaded annual mean temperature and precipitation projection model outputs and recent historical means (1979–2013) in geoTiff format from the Climatologies at High Resolution for the Earth's Land Surface Areas database (CHELSA; Karger et al. 2018, not paginated; Karger et al. 2017, entire). CHELSA is a repository of global climate model outputs downscaled to high spatial resolution (560m; Karger et al. 2018, not paginated; Karger et al. 2017, entire).

For future projections, we used CHELSA data from climate models (Table A2.1) belonging to the Climate Model Intercomparison Project Phase Five (CMIP5). These are models built by independent research groups worldwide, but within standards that allow climate scientists to compare differences in model results in consistent ways (National Center for Atmospheric Research Staff 2016, unpaginated). We included models whose infrastructures (code, model assumptions, and parameterization) are relatively unrelated (Sanderson et al. 2015, p. 5184; www.chelsa-climate.org/future). This helps maximize the benefits of including multiple models by maximizing their independence, the recommended approach for limiting potential bias inherent to individual models' designs. We used a total of seven models, above the recommended minimum of five (www.chelsa-climate.org/future).

Table A2.1—The seven global climate models used for computing future projections of Ponto-Caspian regional mean annual temperatures and precipitation

Model name	Research institute
CESM1-BGC	University Consortium for Atmospheric Research
MPI-ESM-MR	Max Planck Institute for Meteorology
ACCESS1-0	Australian Research Council Centre of Excellence for Climate System Science
MIROC5	Center for Climate System Research, University of Tokyo & other Japanese environmental science institutions
CMCC-CM	The Euro-Mediterranean Center on Climate Change
CESM1-CAM5	University Consortium for Atmospheric Research
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France

Using the geographic information system software ArcMap 10.7.1 (ESRI; Redlands, CA) we cropped model outputs to the extent of each basin (Fig. 3.15). Within this area of interest, we then averaged the future temperature and precipitation projections across all seven models and subtracted the corresponding mean annual temperatures and precipitation for 1979–2013. Subtracting the historical mean values from corresponding projected temperature and precipitation projections gives the projected change in temperature and precipitation.

We repeated the analyses for each of two Representative Concentration Pathways (RCPs), RCP4.5 and RCP8.5. These are United Nations Intergovernmental Panel and on Climate Change (IPCC) scenarios that describe alternative future trajectories of greenhouse gas emissions and are used to drive climate models and projections in response to higher or lower future emission rates (IPCC 2014, p. 8). The values 4.5 and 8.5 refer to the rate at which energy is trapped by Earth's atmosphere in watts per m^2 at the height of warming for the given scenario; thus, RCP8.5 is a scenario indicating faster warming than RCP4.5. RCP8.5 is considered a "high-emission business as usual scenario;" i.e., towards the upper end of what might occur without climate change mitigation policy (Riahi et al. 2011, p. 54). RCP4.5 is based on a lower-emissions future in which renewable energy, greater energy efficiency, and carbon capture and storage are more widely implemented (Thomson et al. 2011, p. 77).

Table A2.2—Projected magnitude of temperature and precipitation changes for the Caspian, Black, and Aral Sea basins for the years 2041 – 2060 relative to the 1979–2013 mean. The ranges shown are basin-wide mean projections from R.C.P. 4.5 and R.C.P. 8.5. Data are summarized from Karger et al. 2018, not paginated; Karger et al. 2017, entire. Larger and smaller magnitudes of change are projected within each basin.

	Temperature (°C)
Caspian Sea basin	2.2 ± 0.3 – 3.0 ± 0.3
Black Sea basin	2.0 ± 0.2 – 2.8 ± 0.2
Aral Sea basin	2.1 ± 0.1 – 2.8 ± 0.2
	Precipitation (%)
Caspian Sea basin	103 ± 2.1 – 103 ± 2.8
Black Sea basin	100 ± 2.6 – 102 ± 2.0
Aral Sea basin	105 ± 2.6 – 106 ± 2.0