Species Status Assessment for the Amur sturgeon (*Acipenser schrenckii*)

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EXECUTIVE SUMMARY

We (the US Fish and Wildlife Service; Service) received a petition dated March 8, 2012 to list Amur sturgeon (*Acipenser schrenckii* Brandt, 1869), a large fish native to the Amur River basin in Russia and China, as threatened or endangered under the U.S. Endangered Species Act of 1973, as amended (Act). We made a substantial 90-day finding on September 24, 2013 (78 FR 58507) indicating that the petitioned action may be warranted.

This document is an evaluation of the present and future conservation status of Amur sturgeon and follows the Species Status Assessment (SSA) framework we developed for review of species' biology and extinction risk. We analyzed the best available scientific and commercial data on the status of the species and projected the status into the future under four alternative threat and conservation scenarios.

It is important to be clear that 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.

Amur sturgeon live up to 60 years, and begin reproducing after 9–14 years. The species was historically abundant along the full length (~3000 km) of the Amur River and most or all of its many large tributaries. Since at least the late 1800s, intensive fishing pressure, first for domestic Russian and Chinese consumption, later to fulfill international demand for caviar (unfertilized sturgeon eggs), has caused dramatic declines estimated by experts to have reduced the species' abundance by more than 95%.

In response to these declines and as early as 1923, Russian and Chinese laws have aimed to strictly limit sturgeon harvest, but the effectiveness of these interventions has been limited. Corruption within fisheries and enforcement agencies, organized crime, international smuggling efforts, and a robust black market for caviar have continued to put the species at risk. These stressors have already caused the extirpation of Amur sturgeon from much of the western (upstream) portion of the Amur River and several of its major tributaries (e.g., the Zeya, Bureya, and Songhua Rivers).

Chinese efforts to farm Amur sturgeon grew tremendously following the 1998 listing and consequent regulation of global sturgeon trade under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). However, there has been limited effort and no evidence of success in using this farming capacity to restore wild populations. Meanwhile, from 1998–2015, the United States was the world's largest importer of sturgeon products (those from the whole Acipenseridae family, and 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, and more recently of live Amur sturgeon traded internationally for use in aquaculture.

Overfishing remains the major threat facing the species. Lesser threats include the construction of dams that impede habitat connectivity, water pollution, climate change, and hybridization of wild fish with fish escaped from aquaculture facilities.

In this SSA, 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 natural demographic and environmental variability (stochasticity); it is improved in large, connected populations. Highly **redundant** species have a large number of populations, which safeguards against rare, localized catastrophic events. **Representation** is a measure of the species' capacity to adapt to changing environments. The current condition of Amur sturgeon is summarized in table ES1.

TABLE ES1—SUMMARY OF CURRENT AMUR STURGEON RESILIENCY, REDUNDANCY, AND REPRESENTATION	
Resiliency (Large, connected populations; reproducing and able to withstand demographic stochasticity)	• Total Amur sturgeon abundance is estimated to be < 5% its size in 1960. • Most (~ 95%) spawning fish are harvested each year. • Water quality is low in some parts of the range. • Connectivity between feeding and spawning grounds is interrupted by dams over major portions of the historically inhabited range, although currently inhabited areas are mostly unobstructed.
Redundancy (number and distribution of populations to withstand catastrophic events)	• The species is extirpated from upstream sections of the Amur River, several major tributaries, and is nearly so from the middle portion of the river. This limits its ability to withstand catastrophic events such as large chemical spills, which have occurred previously in the species' range.
Representation (Ecological and genetic diversity; maintenance of adaptive potential)	• Little is known regarding current or historic levels of genetic diversity and adaptive potential, but population declines of the degree observed in Amur sturgeon are generally accompanied by decreased genetic variability at the population level. This likely limits the adaptive potential of the species.

We forecast the future condition of Amur sturgeon for the year 2050 under each of four plausible scenarios for each of four analysis units—areas of the river basin considered to historically have had at least partially separate populations (Table ES2). Specifically, we built demographic models to project future population sizes based on the best available estimates of current Amur sturgeon abundance and demographic rates, and in light of varying harvest levels and restocking efforts. One scenario also included qualitative assessment of the response of fish to potential construction of a dam on the main stem of the Amur.

TABLE ES2—RESILIENCY OF AMUR STURGEON ANALYSIS UNITS AT PRESENT AND UNDER FOUR ALTERNATIVE FUTURE SCENARIOS

Analysis unit	Current condition	*Status quo* future	Restocking with fry	Restocking with 1-year-old fish	Main stem dam construction
Amur estuary	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**
Lower Amur	**Low**	**Low**	**Low**	**Moderate**	**Very Low-to-Low**
Middle Amur	**Very Low**	**Very Low**	**Very Low**	**Low**	**Extirpated**
Upper Amur	**Extirpated**	**Extirpated**	**Very Low**	**Moderate**	**Extirpated**

At present, we do not consider any analysis units to be self-sustaining; one of four is already extirpated and a second is nearly so. Moreover, regardless of which of four plausible future scenarios we employ, we do not project there to be any self-sustaining analysis units. Construction of a long-proposed dam in the lower Middle Amur's main stem is projected to cause extirpation of a second unit.

Restocking efforts have historically used very young fish fry (~1 month old), but our analyses indicate that plausible restocking levels will not improve the condition of Amur sturgeon if such young fish continue to be used. In contrast, restocking with a lower number of year-old fish, which have much lower mortality than fry do, is projected to retain three units with moderate levels of **resilience** and one with low **resilience**. This would be an improvement to the species' condition.

In 2 of the 4 scenarios, based purely on the number of extant analysis units, we forecast **redundancy** to increase. However, the critically small projected population size (< 200 reproductive females) of some units puts the species at high risk of reduced **redundancy** in the event that random or rare events cause further extirpations. Dam construction would reduce **redundancy** by causing one unit's extirpation.

We have limited information about Amur sturgeon's adaptive potential, but expect that it is low compared to historical levels, given the historical decline in population size. If sturgeon that escape from the region's vast aquaculture operations mate with wild Amur sturgeon, adaptive genetic variation may be lost, reducing **representation**. In addition under *status quo*, fry-restocking, and dam construction scenarios, we expect further decreases in **representation** as the total population size would decline, likely (with 66–89% probability) eliminating some genetic variation. The **representation** effects of restocking using year-old fish are uncertain; some populations will decrease in size, but others will grow.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

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CHAPTER 1—INTRODUCTION

Amur sturgeon (*Acipenser schrenckii* Brandt, 1869; Fig. 1.1) are large fish native to the Amur River basin in Russia and China (Krykhtin and Svirskii 1997, pp. 231–232). They have historically been heavily fished for meat and caviar (Koshelev et al. 2014a, pp. 1312–1316; Wei et al. 1997, pp. 244–246). In 2012, the species was petitioned for listing under the Endangered Species Act of 1973, as amended (Act). We (the U.S. Fish and Wildlife Service; Service) published a substantial 90-day finding indicating that the petitioned action may be warranted on September 24, 2013 (78 FR 58507).

Figure 1.1—Amur sturgeon. *Photo by Javontae Murphy, reproduced under Creative Commons Attribution-Share Alike 3.0 license.*

We use the Species Status Assessment (SSA) framework (Smith et al. 2018, entire) to review the species' biology and its conservation status in light of the threats 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 long-term viability. The SSA report is intended to be updated as new information becomes available and to support relevant actions under the Act into the future.

In this SSA, 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 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.

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 may have differing interpretations of risk, in Appendix I we calibrate our likelihood statements used throughout the text to help standardize discussion of uncertainty.

CHAPTER 2—BIOLOGY OF AMUR STURGEON

Taxonomy and evolutionary history

Amur sturgeon is one of 27 species of sturgeon in the family Acipenseridae (Fricke et al. 2019, not paginated). The synonyms *Acipenser schrenki* and *Acipenser schrenkii* are sometimes used, but are now considered invalid (Fricke et al. 2019, not paginated; ITIS 2019, not paginated). The species is most closely related to Chinese sturgeon, Yangtze sturgeon, and white sturgeon (*A. sinensis*, *A. dabryanus*, and *A. transmontanus*, respectively; Krieger et al. 2008, Fig. 1). We are not aware of any taxonomic disputes regarding the validity of Amur sturgeon as a species.

Sturgeon are closely related to the paddlefish (Polyodontidae), and together these families are the modern members of an evolutionarily basal lineage (Acipenseriformes) that diverged from other ray-finned fish (Actinopterygii) at least 200 million years ago (Billard and Lecointre 2001, pp. 362). For reference, this was 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). Today, sturgeon are distributed only in the northern hemisphere (Billard and Lecointre 2001, pp. 356). All species breed in freshwater, while some migrate into marine habitats (Billard and Lecointre 2001, pp. 356).

Physical description

Amur sturgeon are large fish reaching up to 3 m length and 190 kg weight (Zhuang et al. 2002, pp. 659). They have a downward-facing mouth, cartilaginous skeleton, and a series of bony plates in rows along their back (Billard & Lecointre 2001, pp. 363). Tactile barbels hang from the mouth and may be more important sensory organs than their small eyes (Billard and Lecointre 2001, pp. 359).

Range

Within the Amur basin, Amur sturgeon was historically found as far west as Nerschinsk, Russia in the upper Shilka River (Georgi 1775 cited in Vaisman and Fomenko, pp. 4) and in all of the Onon, Argun, Zeya, Bureya, Nen (Nenjiang), Nerch, Songhua (formerly Sungari), and Ussuri (Wusuli) Rivers, all tributaries of the Amur (Fig. 2.1). The species may also be present in very small numbers in Lake Khanka in extreme southeast Russia (Ruban and Qiwei 2010, not paginated), although few authors confirm this. Today, Amur sturgeon are extirpated from many of these locations, particularly in the upstream (western) reaches of the range and in more heavily developed tributaries of the Amur (see Chapter 4—Current Status of Amur sturgeon). The species occurs at low densities in the southern (and possibly northern) Sea of Okhotsk, but whether individuals there migrate into the Amur River to spawn, do so in another river, or perish at sea without mating is not known (Hagihara et al. 2018, pp. 9). Very rarely, Amur sturgeon are found in the Sea of Japan (Koshelev et al. 2014a, pp. 1313).

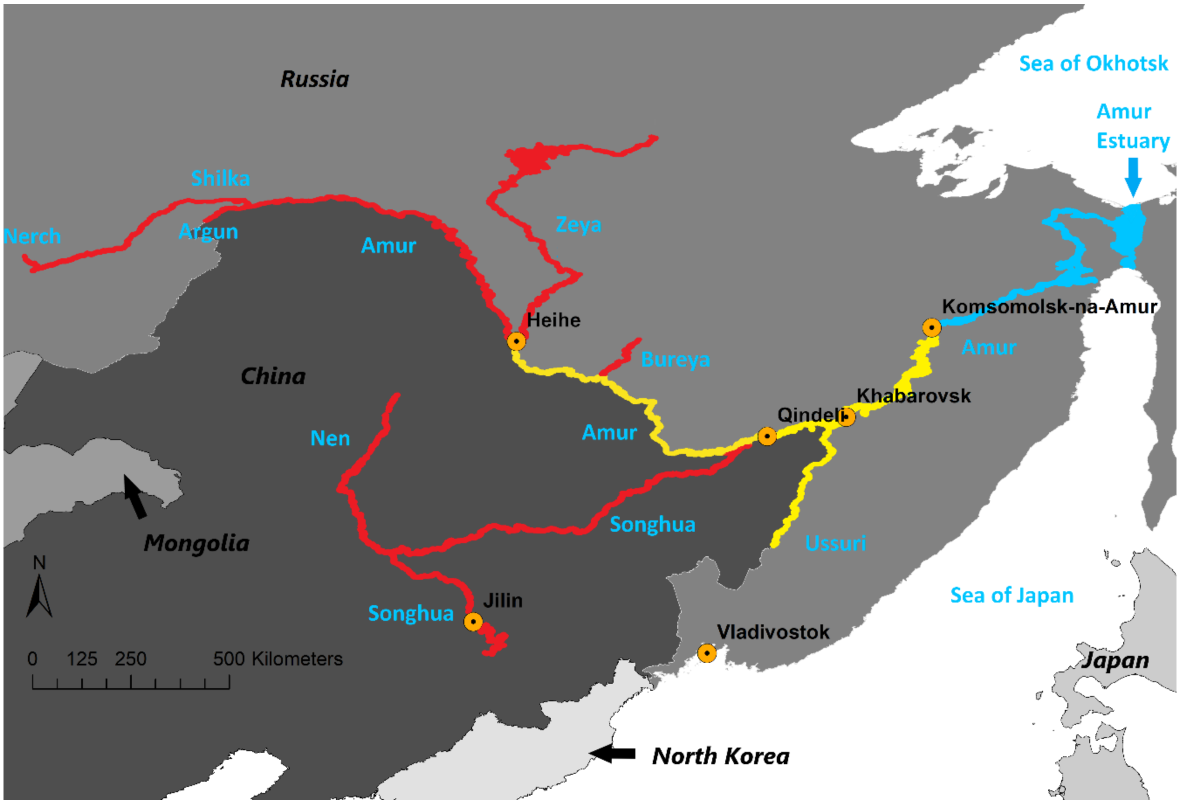

Figure 2.1—The range of Amur sturgeon in the Amur River basin. Shown are the Amur River, whose upstream reaches follow the border of China and Russia, and its major tributaries. Amur sturgeon inhabited all rivers depicted, but red segments are stretches where Amur sturgeon are extirpated and yellow segments are stretches where the species is nearly extirpated. River polyline data are from the open source Digital Chart of the Word (1996). National boundaries are from the Global Administrative Areas (2012) database.

Reproduction

Amur sturgeon—like other sturgeon—are slow to mature (Fig. 2.2). Males require 7–12 years and females 9–14 years before reproduction (Novomodny et al. 2004, pp. 19; Zhuang et al. 2002, pp. 659). This long time to maturation limits the ability of the species to recover from natural or anthropogenic disturbance (see **resilience**, defined below). However, individuals can live up to 60 years (Krykhtin and Svirskii 1997, pp. 236) and females reproduce approximately every 4 years (Ruban and Qiwei 2010, not paginated; Vaisman and Fomenko 2006, pp. 5; Krykhtin and Svirskii 1997 pp. 236). Males spawn every 3–4 years (Ruban and Qiwei 2010, not paginated).

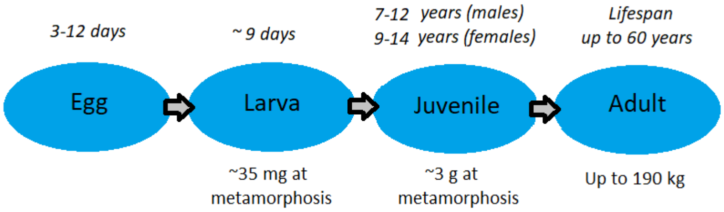

Figure 2.2—Amur sturgeon life stages, their lengths (above ovals), and the weight of individuals in these stages (below ovals). For larva and juveniles, the weights indicate size at entry to these stages; for adults, the maximum attainable size is given. Values from Krykhtin & Svirskii 1997, pp. 236–237; Wei et al. 1997, pp. 244; Zhuang et al. 2002, pp. 659–661.

Prior to spawning, adults migrate upstream in small groups of 3–5 fish (Krykhtin and Svirskii 1997, pp. 237). Most spawning fish migrate beginning in mid-May, as ice covering the river thaws (Koshelev et al. 2014b , pp. 1126; Zhuang et al. 2002, pp. 659; Wei et al. 1997, pp. 245). A smaller number of reproductive fish migrate to spawning grounds the previous fall (mid-August to late September; Ruban 2020, pers. comm.).

Spawning occurs following migration, between May and September. Amur sturgeon prefer to spawn in water of 15–20°C (Wei et al. 1997, pp. 245) and over either sand or gravel substrates 0.5–11 m below the surface (Zhang 1985, Wei et al. 1997, and Krykhtin and Svirskii 1997 cited in Zhuang et al. 2002, pp. 660; Billard and Lecointre 2001, Table 4). Ideal water flow rates are between 0.5–2 m/s (Billard and Lecointre 2001, pp. 360).

Known spawning sites are primarily in the middle Amur River (Wei et al. 1997, pp. 245). This is consistent with evidence that the population of Amur sturgeon was historically greatest in this stretch of the river (Krykhtin and Svirskii 1997, pp. 237). The exact distance which fish move upstream is unclear, although fish appear to spawn within the same river regions (Lower, Middle, Upper) as those in which they spend the rest of the year (Ruban and Qiwei 2010, not paginated; Novomodny et al. 2004, pp. 18). Few migrations are greater than 500 km in length, although some estuary fish travel 1000 km or more into the river (Novomodny et al. 2004, pp. 18) and may spend up to two years there prior to reproducing (Krykhtin and Svirskii 1997, pp. 237).

Females can lay upwards of 1.3 million eggs in a single spawning, although the norm is between 190,000 and 300,000 (Koshelev et al. 2014b, pp. 1127; Zhang 1985 cited in Zhuang et al. 2002, pp. 660-661). A mean of 287,780 ± 24,489 (1 standard deviation) eggs from 317 females was reported (Krykhtin and Svirskii 1997, pp. 237). In related sturgeon species, eggs remain fertile for up to an hour after laying, but sperm are motile for only 1–2 minutes (at least some sturgeon species; Billard and Lecointre 2001, pp. 360). No such data exist for Amur sturgeon, specifically, but it is very likely critical that males and females spawn in close proximity.

Because Amur sturgeon spawning areas overlap in places with those of the related and almost entirely sympatric kaluga sturgeon (*Huso dauricus*), some hybrid offspring are produced (Azuma et al. 2016, pp. 143; Zhang 1985 cited in Zhuang et al. 2002, pp. 660), although these animals may be sterile (Billard and Lecointre 2001, pp. 369). Nearly 80% of these hybrids are also male (Krykhtin and Svirskii 1997, pp. 237).

Development and growth

Most detailed ecological data on the early life history of Amur sturgeon come from laboratory trials, and these data should be taken with some caution, as wild individuals may behave differently (Nikolskii 1960 cited in Zhuang et al. 2003, pp. 46). Larva hatch from eggs after as little as 83 hours at 24 °C, but can take up to 2 weeks when water temperatures are cooler (12 °C; Krykhtin and Svirskii 1997, pp. 237). In the wild, larva are thought to drift downstream for several days before they begin feeding around 9 days post-hatching (Zhuang et al. 2003, Fig. 5; Krykhtin and Svirskii 1997, pp. 237). Tank experiments suggest that larva prefer open river bottoms, likely those with light-colored substrates (Zhuang et al. 2003, Table 2). They also tend to swim 1.0–1.5 m above the substrate for the first 3 days post-hatching, before moving downwards to 0–0.45 m above the substrate. Juveniles move to the shallow shoreline and into smaller tributaries and lakes where they likely feed in the extensive, flat, sandy areas of shallow water (Zhuang et al. 2002, pp. 659). Juveniles may also be more sensitive to salinity than are larger individuals, although Amur sturgeon are generally rare in areas of the estuary with salinity over 7.5ppt (Koshelev et al. 2014a, pp. 1314).

Sturgeon are heavily r-selected species; i.e., despite high fecundity, they have very high mortality of early life stages. In related species of sturgeon, survival of fish through their first year is estimated to be no higher than approximately 1 in 2000 for related species (Jaric and Gessner 2013, Table 1; Jager et al. 2001, Table 1). Juvenile fish survive at much high rates (20–90% per year for several *Acipenser* spp.; Jaric and Gessner 2013, Table 1; Jager et al. 2001, Table 1). Although similar survival data are not available for Amur sturgeon, consultation with a Service sturgeon expert confirms the species very likely has similar patterns of survival by age (Kappenmann 2020, pers. comm.).

Larva hatch from eggs at approximately 1 cm in length (Zhuang et al. 2002, pp. 661). After about 30 days (Fig. 2.2), they metamorphose into juvenile fish of about 4 cm length and 3 g weight (Zhuang et al. 1999a and Liu et al. 2000 cited in Zhuang et al. 2002, pp. 661).

Amur sturgeon continue growing for several decades. By 1 year of age, fish average approximately 30 cm (Nikolskii 1960 cited in Zhuang et al. 2002, pp. 660). Six-year-old individuals may be 90 cm, 25-year-old fish 2 m, and large 40-year-old fish will approach 2.5 m (Zhang 1985 cited in Zhuang et al. 2002, pp. 660). Amur sturgeon in the estuary are smaller and grow more slowly than those found upstream of Qindeli, China (Zhuang et al. 2002, pp. 659-660; Wei et al. 1997, pp. 244), possibly indicating ecological, genetic, or life history diversity that could improve the species' adaptive capacity (see **representation** below). In addition, there is a rare brown morph that grows more slowly than the more common gray morph (Zhuang et al. 2002, pp. 660).

Diet

Amur sturgeon prey on larval insects, small mollusks, crustaceans, and fish (Novomody et al. 2004, pp. 19; Nikolskii 1960 and Sun et al. 2000 cited in Zhuang et al. 2002, pp. 660). There is geographic and age-based variation in preferred food items. In some locations, Arctic lamprey (*Lampetra japonica*) larva are particularly common prey (Krykhtin and Svirskii 1997, pp. 236) and invertebrates are especially important in the winter and for juvenile sturgeon (< 75 cm total length; Sun et al. 2000 and Nikolskii 1960 cited in Zhuang et al. 2002, pp. 660). Larger individuals eat a more fish-heavy diet (Nikolskii 1960 cited in Zhuang et al. 2002, pp. 660), but in the estuary, larger individuals (> 100 cm fork length, snout to center of tail fin split) prefer mollusks (53% of their diet), mostly of the genus *Corbicula*. Smaller Amur sturgeon in the estuary are more piscivorous and focus on pond smelt (*Hypomesus olidus*; Kolybov and Koshelev 2014, pp. 489). In the river, some sturgeon may almost exclusively eat insects (Yukhimenko et al. 1963 cited in Kolobov and Koshelev 2014, pp. 490).

Population biology

Little information exists on the population biology of Amur sturgeon, although the fish are believed to spawn within the same larger river regions as those in which they feed throughout the year (Ruban and Qiwei 2010, not paginated; Novomodny et al. 2004, pp. 18). Therefore, we follow the limited literature (e.g., Koshelev et al. 2014a, entire; Krykhtin and Svirskii 1997, pp. 236–238) and consider fish in four river regions to be the analysis units for our assessment of the species' status.

- Amur estuary, inclusive of the few individuals found in the Sea of Japan and Sea of Ohkotsk;
- Lower river, from Khaborovsk (Russia) to the mouth of the river where it meets the estuary;
- Middle river, from Heihe (China) to Khaborovsk, inclusive of the Zeya and Bureya Rivers, both northern tributaries of the Amur;
- Upper river, upstream of Heihe, inclusive of the Shilka and Argun rivers whose confluence form the Amur headwaters.

Although the exact migration routes, spawning locations, delineations between, and levels of interbreeding among fish from these regions are not known, there are clearly different breeding stocks, separated by time and location. For instance, fish from the Zeya and Bureya breed in the Upper and upper Middle Amur (Krykhtin and Svirskii 1997, pp. 235–236), whereas fish from the estuary and lower river migrate upstream to breed between Luobei, Xunke, and Tongjiang counties along the lower Middle Amur (Wei et al. 1997, pp. 245).

All Estuary fish that reproduce do so only after having migrated upstream into the river-. Those that do not reproduce in a given year do not migrate (e.g., Koshelev et al. 2014a, entire; Krykhtin and Svirskii 1997, pp. 236–238). Some may spend up to two years in the river before reproducing and returning to the estuary to mature (Krykhtin and Svirskii 1997, pp. 237).

We use the analysis units to describe what we believe to be regions where Amur sturgeon are likely to have reproduced in at least partially distinct populations, where they may face different conservation threats, and where their status may be different. Because there is much uncertainty regarding the structure of Amur sturgeon populations (e.g., movement and breeding among analysis units, metapopulation dynamics), for the remainder of this report, where we use the word "population" it is meant only in its most general sense—a group of individuals of the same species.

As mentioned above, two Amur sturgeon color morphs exist, a common gray one and a rare brown one that lives in the Middle and Lower Amur (Krykhtin and Svirskii 1997, pp. 236). The presence of two morphs (Krykhtin and Svirskii 1997, pp. 236) indicate some level of ecological or genetic diversity (see **representation below)** in Amur sturgeon. The two morphs do inter-breed (Billard and Lecointre 2001, pp. 372), but the exact genetic and ecological relationships between the two morphs remains uncertain (Ruban & Qiwei, 2010, not paginated).

Resiliency, redundancy, and representation

Based on the life history described above, the ecological needs of Amur sturgeon at the individual, population, and species level are summarized in Table 2.1. We consider these needs in the context of the 3Rs—**resiliency**, **redundancy**, and **representation**—to determine the condition of the species at present and under four plausible future scenarios (Chapters 4 and 5). **Resilience** is scored by assigning numerical values to criteria that inform each analysis unit's status in light of the in-depth discussion in Chapter 3 of these units' condition and the threats to them. In particular, we consider four critical elements to characterize the **resilience** of populations: the number of reproductive females, their likelihood of surviving to reproduce multiple times, water quality, and the connectivity of spawning and feeding grounds.

Table 2.1. Summary of Amur sturgeon's ecological needs.

Individual	Population	Species
Water of suitable temperature for hatching and development; possible at 12–24 °C, and likely a wider range	Connectivity of feeding and spawning grounds	Adaptive capacity (genetic and/or ecological variation) to respond ecologically and/or evolutionarily to changing environments.
Well-oxygenated water for respiration	Sand or gravel substrates 0.5–11m below the surface of water flowing at 0.5–2m/s	Distinct and/or wide-ranging populations make the species less susceptible to catastrophic disturbances.
Abundant prey: larval insects, small mollusks, crustaceans, & fish	7–14 years survival to reproduction	
Salinity < 7.5 ppt, esp. for juveniles		
Low-turbidity, unpolluted water		
See citations in the main text for all needs listed.		

In Table 2.2, we define the numerical values for scoring the current and future **resilience** of Amur sturgeon analysis units based on each of the four **resilience** criteria. We summed these scores to obtain overall resiliency scores for each analysis unit and considered total scores of 4 and lower to indicate very low **resilience**, 5–6 low **resilience**, 7–10 moderate **resilience**, and 11–15 high **resilience**. In the case that any unit has less than 200 mature females, it is classified as of very low resilience, regardless of the condition of the other three criteria.

Thresholds for scoring the abundance of reproductive females were based on our estimates of historical population sizes (see *Appendix III*). These approximations were made by converting historical fisheries landing volumes to estimates of the number of fish caught and extrapolating to total abundance of reproductive females. Where there was uncertainty in the process of making these estimates (e.g., in the average historical size of captured Amur sturgeon), we deliberately used (often highly) conservative options. This decision, if anything, biases our estimates of historical population sizes downwards and encourages scoring of depleted current and future populations as relatively resilient compared to the historical condition (again, see *Appendix III*).

Because both readers and decision-makers may have differing interpretations of risk we calibrate our categorical rating of resilience to help standardize discussion of uncertainty. Therefore, we define our language regarding resiliency. High-**resilience** units are those in a self-sustaining condition and experiencing little-if-any risk of extirpation. Moderately resilient units are unlikely to be self-sustaining and are experiencing some level conservation threat which could eventually lead to extirpation. Low- and very low-**resilience** units are not self-sustaining, due to ongoing conservation threats; they may become extirpated, perhaps rapidly in the case of very low-**resilience** units.

Table 2.2. Criteria and scoring metrics for Amur sturgeon analysis unit resiliency.

Resilience criteria	Definition of conditions
Number of reproductive females *(see Appendix III for justification of thresholds)*	High: 6 points for at least 34,000 reproductively mature females; Medium: 4 points for 10,000–33,999 reproductively mature females; Low: 2 point for 1000–9,999 reproductively mature females; Very low: 0 points for less than 1000 reproductively mature females. **Any unit with < 200 mature females is classified as of very low resilience, regardless of the condition of other criteria.
Water quality to support prey availability and sturgeon health	High: 3 points for high water quality enabling abundant food resources (insects, mollusks, crustaceans, small fish), and creating no known threats to fish health. Medium: 2 points for moderate water quality, possibly impacting sturgeon health and the abundance of food resources. Low: 1 point for heavy pollution at least likely to be causing strong negative impacts on sturgeon health and food resources. Extirpated: 0 points for any extirpated population.
Survival and growth of females to reproduce multiple times	High: 3 points where most females survive to reproduce multiple times. Medium: 2 points where few females survive to reproduce multiple times. Low: 1 point where few females live to sexual maturity. Extirpated: 0 points for any extirpated population.
Connectivity between spawning and feeding grounds	High: 3 points for no barriers to connectivity. Medium: 2 points for barriers to connectivity limited to tributaries of the main river within the analysis unit's range. Low: 1 point for barrier(s) to connectivity in the main river within the analysis unit's range. Extirpated: 0 points for any extirpated population.
Note that extant populations cannot score fewer than 3 points.	

CHAPTER 3—THREATS TO AND CONSERVATION MEASURES FOR AMUR STURGEON

Unsustainable harvest for caviar and meat consumption is the foremost threat to the viability of Amur sturgeon populations (Vaisman and Fomenko 2006, entire; Zhuang et al. 2002, pp. 659). Indeed, the Amur River was identified in 2018 as one of the most concerning regions for sturgeon poaching globally (Harris and Shiraishi 2018, pp. 12) and experts estimate that 95% of spawning fish are harvested annually (Simonov and Dahmer 2008, pp. 47). Caviar consumers prefer products from rarer species, meaning the market could easily drive the species to extinction (Gault et al. 2008, Fig. 2), since caviar collection requires lethal harvest of mature females (Van Eenennaam et al. 2004, pp. 302). Therefore, this chapter focuses first and foremost on the threat posed by overfishing, before considering dam construction and pollution (secondary but also major threats), as well as disease, hybridization with escaped aquaculture fish, and climate change, which presently pose lesser risk to Amur sturgeon.

Overfishing and the trade in Amur sturgeon caviar and meat (see also Table A2.1)

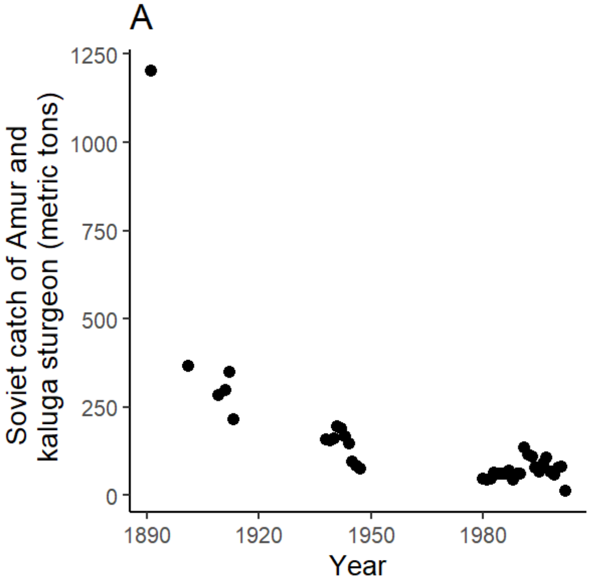

Figure 3.1—Historical legal catches of Amur and kaluga sturgeon by Soviet fisheries between 1891 and 2002. Note that although commercial Amur sturgeon fishing is banned in Russia since 1984, catches here include "test fishing," the state-sanctioned harvest ostensibly for population monitoring; much of the fish caught in this manner is believed to be illegally sold (Vaisman and Fomenko 2006, pp. *v*). Data from Krykhtin and Svirskii 1997, Soldatov 1915, Svirskii 1971, VNIRO 2000–2005 (unpublished), all cited in Vaisman and Fomenko 2006, Tables 3–5.

Russian overharvest and sales fueled by corruption

Historically, Amur sturgeon were harvested in Russia only for local consumption (Maak 1861 cited in Vaisman and Fomenko 2006, pp. 11). Still, unsustainable harvesting practices led to population declines and crashes in the annual harvest volume as early as the late 19th century (Fig. 3.1; Vaisman and Fomenko 2006, pp. 11).

In 1891, 607 metric tons of Amur sturgeon were harvested from the Amur basin (Kryukov 1894 cited in Krykhtin and Svirskii 1997, pp. 231), but by 1909 only about 20% of this volume was caught (Krykhtin and Svirskii 1997, pp. 231). In 1948, only 4.2 metric tons were caught (Krykhtin and Svirskii 1997, pp. 232) and in the early 2000s, legal harvests could still barely reach 10 metric tons (Vaisman and Fomenko 2006, pp. 16).

While commercial fishing for sturgeon is technically banned in Russia today (Harris and Shiraishi 2018, pp. 9; see *Domestic fisheries regulation—Russia* in Chapter 5), the country has long permitted legal harvest of Amur sturgeon. Known as "test fishing" or "controlled catches," these state-sanctioned harvests are officially for population monitoring and are distinct from any harvest allowed for scientific research (Vaisman and Fomenko 2006, pp. 9–10; CITES 2001a, pp. 35). However, test fishing was used as a cover for rampant fishing and sales of Amur sturgeon at least into the early 2000s (Vaisman and Fomenko 2006, pp. *v* and 9). Officials laundered captured fish into the commercial market, selling confiscated fish (Vaisman and Fomenko 2006, pp. 14) and allowing illicit fishing in return for bribes (Vaisman and Fomenko 2006, pp. 18). Indeed, in 2001, the CITES Standing Committee (CITES 2001a, pp. 35) wrote, "The purpose of the system of 'controlled catches' …and the establishment of quotas for controlled catches, remain unclear and further explanation should be provided."

Despite supposedly strict test fishing quotas, Russian authorities continued to certify as approved for human consumption far greater volumes of Amur sturgeon than allowed (Fig. 3.2; Vaisman and Fomenko 2006, Table 8). For example, between 2000 and 2002, Russian authorities certified for export over seven times the amount of caviar from kaluga and Amur sturgeon as could have been harvested from the legal quota of wild fish (many fishery records combine data for kaluga and Amur sturgeon; Fig. 5 and Vaisman and Fomenko 2006, pp. 14). In 2004 and 2005, no quota was allowed for legal fishing, but over 1700kg of Amur sturgeon was certified (Vaisman and Fomenko 2006, pp. 26).

Experts estimate that in the early 2000s, up to 750 metric tons (1.7 million pounds) of Amur sturgeon were illegally harvested each year in Russian waters (Erickson et al. 2007, pp. 31), and interviews with poachers and with other local residents reveal that reported catch data underestimate actual harvests (Vaisman and Fomenko, 2006, pp. 16). Interviewees also said that the species became markedly less common between 2002 and 2004 (Vaisman and Fomenko, 2006, pp. 16), and that fishing on the Middle Amur spawning grounds had particularly devastating effects on the population (Krykhtin and Svirskii 1997, pp. 237). Fishing pressure has likely been greater in the river than in the estuary because weather and oceanographic conditions make fishing more challenging in the estuary (Koshelev et al. 2016, pp. 238).

Illegal sturgeon harvesting has been widespread, intense, and sometimes sophisticated. Russian authorities detained over 1000 poachers in just May and June of 2003 (Vladivostok News, June 24 2003). In the first quarter of 2005, over $500,000 worth of Amur and kaluga sturgeon were seized in Russia's Far Eastern Federal District (ECHO Far East News Agency, April 19 2005). Within the region of Khabarovsky-Krai (bordering the Amur River to its northeast, along the Russian far east coast), more than 1000 poaching incidents were identified between 2000 and 2001 (Vaisman and Fomenko 2006, Table 9). Two different estimates have placed the number of boats fishing for sturgeon in the early 2000s at 200 and 3000 (Vaisman and Fomenko 2006, pp. 16; Novomodny et al. 2004, pp. 24–25). Reports of poaching and international smuggling of up to several metric tons of caviar per boat have come from Baidukov Island north of the Amur estuary, the Chastye Islands in the estuary, and the Yevraiskaya Autonomous Oblast, a region several hundred kilometers upstream of the mouth of the Amur (Vaisman and Fomenko 2006, pp. 15).

Fishing technology has advanced as organized crime units have moved to control the harvest of Amur sturgeon in Russian territory, especially in the upper portion of the Lower Amur (Vaisman and Fomenko 2006, pp. 19; Krykhtin and Svirskii 1997, pp. 237). Fishermen began in the early 2000s to use much larger nets and to keep all sturgeon caught, regardless of their size (Vaisman and Fomenko 2006, pp. 16). A small number of poachers in the area of Komsomolsk-na-Amur use high-horsepower boats to fish for sturgeon, enabling quick escape from any law enforcement in the area (Vaisman and Fomenko 2006, pp. 16). Fishermen also paid as little as 650–1000 USD annually, and sometimes handed over parts of their illegal catch to inspectors, in return for avoiding arrest and penalties (Vaisman and Fomenko 2006, pp. 18).

In some cases, extraordinary crimes have been committed to facilitate sturgeon poaching. Violent retribution against fisheries inspectors has occasionally been reported (Vaisman and Fomenko 2006, pp. 19), including the caviar-related killing of over 70 Russian law enforcement officers in the 1990s (Liddick 2014 cited in Harris and Shiraishi 2018, pp. 14). State police have been implicated in sturgeon trafficking, and high-level law enforcement, administrative, and defense officials were complicit in the illegal Amur sturgeon trade (Vaisman and Fomenko 2006, pp. 19). Fish are illegally transported by train, boat, plane, and car, including inside a coffin and hearse in one case (Harris and Shiraishi 2018, pp. 33; Vostok Media, November 13 2015; Vaisman and Fomenko 2006, pp. 23–30). In 2016, 88 frozen sturgeon carcasses were confiscated from a Moscow address after being transported from the Amur region (*Moktu Russia* 2016, not paginated; Harris and Shiraishi 2018, Annex II). In another instance, nearly 1 metric ton of sturgeon caviar (approximately 10 million eggs, equal to the egg content of roughly 35 adult females; Bruch et al. 2006, Table 1; Krykhtin and Svirskii 1997, pp. 237) was seized from organized criminals in the city of Komsomolsk-na-Amur (TBU, October 16 2017). Over a dozen arrests were reported in the media between November 2014 and February 2018.

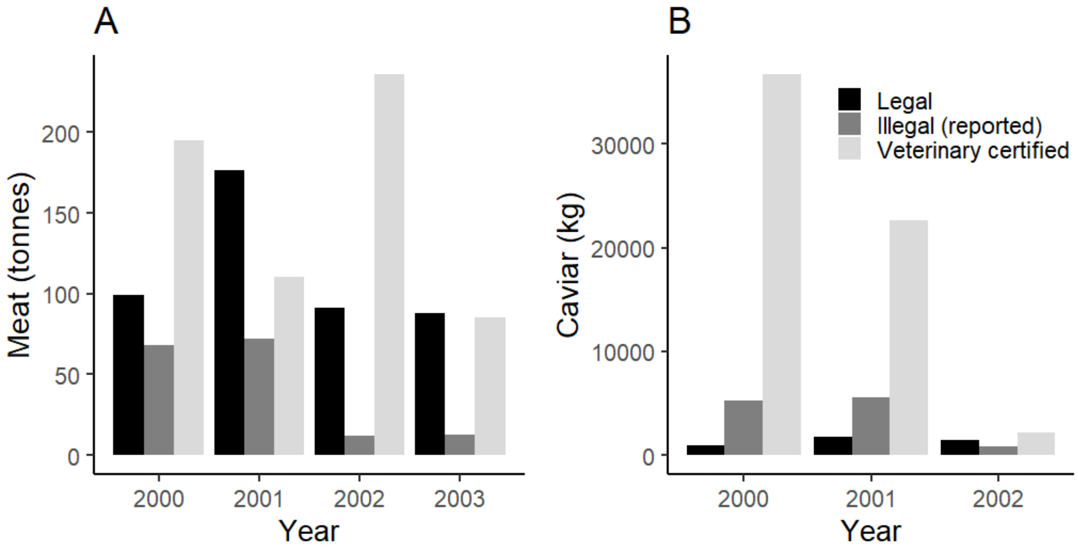

Figure 3.2—Reported Russian catch of Amur and kaluga sturgeon as (A) tons of meat and (B) kg of caviar. Black bars denote legal catches, dark gray bars are reported illegal seizure volumes, and light gray bars are the volume certified by the Regional Directorate of Veterinary Science, a necessary prerequisite for CITES export permission (Vaisman and Fomenko 2006, pp. 14). Note that for meat in 2002 and for caviar in 2000 and 2001, certified products vastly outweigh reported legal plus illegal catch. Data from the Deputy Chairman of the Government and Minister of Natural Resources of Khabarovsky Krai as reported in Table 8 of Vaisman and Fomenko 2006.

In the early 2000s, between 90 and 100% of domestically sold Amur sturgeon was believed to be illegally caught (Harris and Shiraishi 2018 pp. 33; Vaisman and Fomenko 2006, pp. 22). This was aided by the limited nature of fisheries regulations and their enforcement for domestic sale of sturgeon (Vaisman and Fomenko 2006 pp. 18). Nearly every market stall in the city of Khaborosk (pop. > 600,000) sold illegally sourced caviar and one could place an advance order for up to several metric tons of sturgeon meat (Vaisman and Fomenko 2006, pp. 20). By 2018, Khabarovsk residents indicated that sturgeon products remained easy to find on the black market (Harris and Shiraishi 2018 pp. 40), despite recent federal inspections and reports that two markets visited by researchers did not have any sturgeon or caviar products for sale (Harris and Shiraishi 2018 pp. 40).

Mislabeling the origin and species of caviar and sturgeon meat conceals Amur sturgeon and may inflate prices. For instance, DNA-based identification of caviar samples labeled as “oscietra” (usually referring to Russian sturgeon, *A. gueldenstaedtii*, caviar) or “beluga” (*Huso huso*) from nine Moscow vendors found Amur sturgeon in 3 samples and its hybrid with kaluga sturgeon in 3 additional samples (Harris and Shiraishi 2018, Table 9). In two cases, sellers claimed the Amur sturgeon caviar was of wild origin, perhaps to sell it at a higher price, even though it was determined to be from aquaculture (Harris and Shiraishi 2018, Table 9). Some caviar was also marked as wild-sourced beluga sturgeon (*Huso huso*; listed as threatened under the Act), but determined to actually be Amur sturgeon, probably from Chinese aquaculture (Harris and Shiraishi 2018, pp. 60).

Russian domestic regulations

Declines in the catch of sturgeon were concerning enough nearly a century ago (Fig. 4) that the Soviet commercial fishery was shuttered for both Amur and kaluga sturgeon in 1923 (Vaisman and Fomenko 2006, pp. 11). This was the beginning of a complex set of at best questionably effective Soviet (and now Russian) regulations governing the harvest of Amur sturgeon. The original ban remained in place until 1930, then was reinstituted for 1958–1976 and from 1984 to the present (Vaisman and Fomenko 2006, pp. *iv*).

In practice, these have been far from complete bans (see discussion of “test fishing” above). Test fishing quotas were reduced from 15 to 1.3 metric tons between 2006 and 2015 (WWF Russia 2015 cited in Harris and Shiraishi 2018, pp. 34). However, the failure to define and enforce what is allowed under the test fishing regime has been a major impediment to fishery regulation in the past (Vaisman and Fomenko 2006, pp. *v* and 26), and it is unclear to what extent the corrupt aspects of test fishing (overharvest and sale of captured fish) have been addressed.

Amur sturgeon are technically protected from commercial trade in Russia by listing in the country’s Red Data Book, but they were readily available in Russian markets in 2017 and 2018 (Harris and Shiraishi 2018, pp. 9). Recent market inspections have driven some open sale of Amur sturgeon underground in Khaborovsk (Harris and Shiraishi 2018, pp. 40) and beginning in 2020, additional labeling requirements were expected, although stricter control of sales has generally been resisted for fear of harming the aquaculture trade (*Economics & Life* 2017, not paginated).

Russian law does not provide for punishments strong enough to deter poaching. Fishermen can earn a full year's income from sale of a single large fish (Harris and Shiraishi 2018, pp. 40) and fines are too small in comparison (Musing et al. 2019, pp. 20; Erickson et al. 2007, pp. 30; Vaisman and Fomenko 2006, pp. 18). As of 2018, up to 3 years imprisonment was possible (Harris and Shiraishi 2018, pp. 34) but rarely assessed; most arrests led to dismissal of the case before prosecution (Vaisman and Fomenko 2006 pp. 17). Even some Russian prosecutors consider the failure of Russian law to regulate domestic sturgeon trade to be a major obstacle for sturgeon conservation (Vaisman and Fomenko 2006 pp. 18).

Current regulatory measures and law enforcement capacity are not sufficient to protect and recover remaining stocks of the species, given the Russian trade in Amur sturgeon (Vaisman and Fomenko 2006, pp. 26-28; Harris and Shiraishi 2018, pp 33). Inspectors are not paid adequately to discourage their participation in corruption; in the early 2000s, they were paid as little as $100 per year to safeguard Amur sturgeon worth many thousands of dollars (Novomodny et al. 2004; pp. 25).

Developing alternative livelihoods could further the conservation and restoration of the species (Vaisman and Fomenko 2006, pp. 26-28; Novomodny et al. 2004, pp. 28). Indeed, some Russian communities have relied economically on the sale of fewer than 10 sturgeon in an entire season (Vaisman and Fomenko 2006, pp. 16), sug gesting they may be especially receptive to interventions that would decouple their economic wellbeing from sturgeon poaching.

Overharvest in China

Chinese records similarly indicate that overfishing and illicit trade has caused massive population declines in Amur sturgeon (Fig. 3.3), although somewhat less information is available compared to that from the Russian fishery (Wang and Chang 2006, pp. 45). The Chinese catch of Amur and kaluga sturgeon combined increased greatly beginning in the mid-1970s (Fig. 3.3) due to the onset and expansion of the international caviar trade; a large proportion was exported to the United States, Europe, and Japan (Wang and Chang 2005, pp. 45–46; Zhu et al. 2008, pp. 31). After a peak of 461 metric tons in 1981, the catch declined precipitously to an average of just 117 metric tons (SD ± 55) between 1996 and 2002, with just 50 and 25 metric tons caught in the final two years.

Amur sturgeon was by far the most commonly traded sturgeon species in China in the 1990s and early 2000s, with 40,000–50,000 (mostly farmed) individuals traded daily in Guangzhou, Shanghai, and Beijing (Zhu et al. 2008, pp. 31). This demand and the use of wild-caught fish in aquaculture (Simonov and Dahmer 2008, pp. 129; Fig. 3.4; Wei no date, pp. 1) contributed to a crash in Amur sturgeon fisheries yield throughout the 1990s (Fig. 3.3). Legal harvest of wild Amur sturgeon is disallowed in China since 2001 without a permit (Simonov and Dahmer 2008, pp. 130; see Domestic fisheries regulation—China).

Poaching has historically been a lesser problem in China than in Russia, because of the strong law enforcement capacity in China (Novomodny et al. 2004, pp. 24). Fishermen are not allowed to have high-speed boats and corruption was rare (if present at all) as of the early 2000s (Novomodny et al. 2004, pp. 24).

Still, illegal harvest continued, and by 2017, some Chinese residents of the Amur region claimed that the fish's population was so low that there was no longer an active fishery (Harris and Shiraishi 2018, pp. 46). However, other respondents discussed ongoing poaching (Harris and Shiraishi 2018, pp. 46).

Since 2000, Chinese sturgeon farming has grown tremendously to satisfy the global demand for caviar (see *Captive rearing for meat and caviar* and Fig. 3.4) and a reliance of this industry on wild-caught Amur sturgeon was considered by at least one expert to be the primary threat to the species (Wei no date, pp. 1). As of 2008, 70% of all sturgeon fry in Chinese aquaculture came from wild-collected individuals (Simonov and Dahmer 2008, pp. 129; Fig. 3.4). Amur sturgeon were smuggled across the river as live adults and eggs (Vaisman and Fomenko 2006, pp. 24).

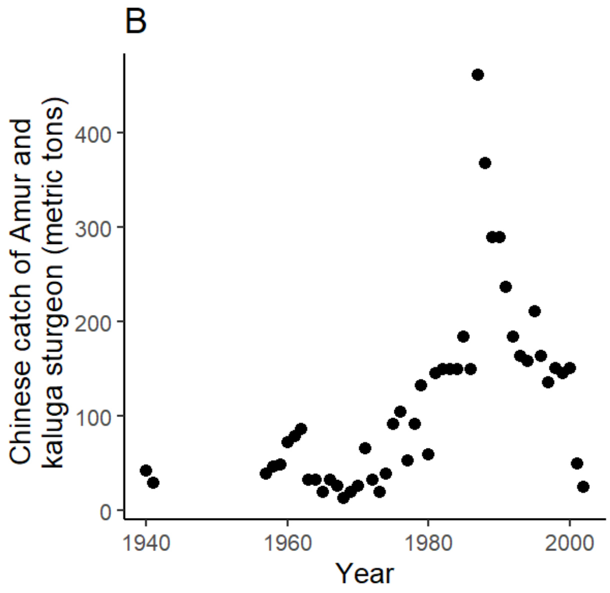

Figure 3.3—Historic legal catches of Amur plus kaluga sturgeon by Chinese fisheries between 1940 and 2002. The increase in the late 1970s and 1980s occurred in response to growing international caviar demand (Wang and Chang 2005, pp. 45–46; Zhu et al. 2008, pp. 31). Data from Nikolsky 1956 and Wei 2001 cited in Vaisman and Fomenko 2006, Table 6.

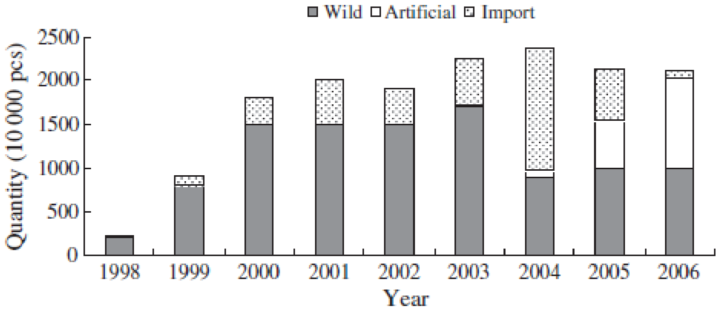

Figure 3.4—Volume of sturgeon larvae used in Chinese aquaculture from each of three source types—wild-caught, artificial (farm-reared), and imported—for each year, 1998–2006. Data are for all sturgeon species in production, not just Amur sturgeon. Reproduced from Li et al. 2009, Fig. 4.

Chinese domestic regulations

Chinese regulation of the sturgeon fishery began as early as the 1950s, but early rules were not effective (Zhang and Li, 2009 pp. 85). Provincial laws limited the capture of Amur sturgeon to individuals at least 1 m in length and 4 kg in weight in 1982 and created a short 25-day ban on fishing each year in June and July (presumably to avoid the spawning season; Wang and Chang 2006, pp. 48). By 2002, temporary bans on Amur sturgeon fishing during the species' migration or spawning were expanded to permanently protect a 5 km stretch of the Amur River from Dagangzi to the Amur-Songhua confluence, which is believed to be an important spawning area (Wang and Chang 2006, pp. 51; Xinhuanet, June 11 2002).

Now, Amur sturgeon is listed as a class-II species under the federal Chinese Wild Animal Protection Law and provincial administrative approval is required for harvest and sale (Harris and Shiraishi 2018, pp 46–47; Wang and Chang 2006, pp. 48). Permits are required for any fishing and may be granted for scientific research, disease monitoring, or other limited reasons (Harris and Shiraishi 2018, pp. 47). Fines can be issued up to 10 times the value of illegally harvested fish, and fishing gear can be confiscated (Harris and Shiraishi 2018, pp. 47). Aquaculture and sale of Amur sturgeon is also only allowed by permit, and sale of wild sturgeon is only allowed for research, breeding, public display, conservation, or other limited reasons (Harris and Shiraishi 2018, pp. 47).

In January 2018, 12 Beijing locations (including five expansive markets) thought to be sturgeon retailers had no sturgeon products for sale. Amur sturgeon caviar was at least occasionally available online from Chinese sellers, though (Harris and Shiraishi 2018, Table 17). The effectiveness of Chinese policies remains somewhat unclear, as few data are available to quantify the volume of any continuing illicit sales and the lack of a labeling requirements for the domestic sale of caviar hinders enforcement efforts targeting illegally caught or imported products misidentified as sourced from aquaculture (Harris and Shiraishi 2018, pp. 48).

International trade in caviar and meat

International demand for sturgeon caviar, and to a lesser extent meat, fuels a cross-continental market for these products and is the primary reason that as of 2017, 85% of sturgeon species were listed as critically endangered or extinct in the wild by the IUCN (Rachler and Reinartz 2017, pp. 1). Russian caviar (including that from Amur sturgeon) is particularly sought-after, and rarer sturgeon are preferred by most consumers (Gault et al. 2008, Fig. 2), although the demand for wild-sourced products may be declining (Harris and Shiraishi 2018, pp. 10).

Over 90% of the Russian caviar trade (all species) may be illegal (Nellemann et al. 2014, pp. 43) and a wide range of ongoing illicit activities was identified in a 2017 report by TRAFFIC and WWF (Harris and Shiraishi 2018, pp. 7):

- Products from likely poached wild fish are sold online, in markets, and through black market contacts;
- Wild-caught sturgeon products are misrepresented as derived from aquaculture and laundered into the CITES-regulated international market;
- Sale of farmed sturgeon products as supposedly wild fish to garner a higher price;
- CITES permits and labels are forged or corruptly obtained (see *CITES and international trade regulation*).

According to data from the CITES Trade Database, between 2015 and 2019, the United States was the largest importer of sturgeon caviar (223,000 kg; all species), with a volume over 80% higher than the share of the next-largest importing country, Denmark. This trend has been consistent. Indeed, the United States has been the largest importer of sturgeon and sturgeon products since 1998, and between 2010 and 2015 was also the second-largest exporter (Harris and Shiraishi 2018, pp. 26; UNEP-WCMC 2012, pp. 22).

The Service's Office of Law Enforcement and its International Affairs program maintain records of import and export of Amur sturgeon, including legal trade and any illegal shipments confiscated on entry to the United States. Between January 2000 and October 2019, the Service recorded 325 imports to the United States, including 33 shipments during fiscal year 2019 (CITES Annual Report Database (CARS) 2020, not paginated). Thirty-one of the 33 imports in fiscal year 2019 were from China, with the remaining two from France, and most were caviar [USFWS Office of Law Enforcement (OLE) Law Enforcement Management Information System 2019 not paginated]. Fewer than half a dozen total meat and chemical extract (likely for cosmetics manufacturing) shipments were recorded (USFWS OLE LEMIS 2019, not paginated).

Fifteen illegal shipments to the United States were seized between 2000 and 2018 (CARS 2020, not paginated). Around 17 metric tons of Amur sturgeon caviar were imported to the US between 2000 and 2019 (CARS 2020, not paginated; CITES and UNEP-WCMC 2019), with about 1.4 metric tons classified as illegal and seized. However, because of the very nature of illegal trade, it cannot be fully captured by the available data.

We do not know how many illegal shipments go undetected; however, at least through the mid-2000s, illegal import of sturgeon products to the United States was common among major caviar retailers (Wyler and Sheikh 2013, pp. 10). Illegal Amur sturgeon products were imported to the United States (as well as Japan, the U.K., Uzbekistan, and elsewhere) in the early 2000s from the Khabarovsk airport in Russia (Vaisman and Fomenko, pp. 23). However, increased law enforcement, including by the Service, and the introduction of CITES labeling requirements in 2004, has improved the situation somewhat. Whereas 23% of caviar items bought from New York retailers were mislabeled in 1995–1996 (pre-CITES listing), this rate dropped to just 10% between 2006 and 2008 (Doukakis et al., 2012 pp. 3–4; Birstein et al. 1998, pp. 771). No Amur sturgeon were found in the mislabeled caviar, although the sample size was not large.

Laboratory methods based on the differential biochemical content of wild versus farmed sturgeon tissues have met with mixed success, and are not regularly employed by law enforcement (DePeters et al. 2013, pp. 130–131; Czesny et al. 2000, pp. 147–148). Correct identification of traded caviar as wild or farmed is very challenging.

In October 2019, an internet search revealed at least half a dozen United States and European companies selling caviar from Amur sturgeon—and more commonly from its hybrid with kaluga sturgeon—in the United States at approximately $1000–$1300 per pound. Amur sturgeon is sometimes marketed as "Japanese sturgeon" or may be sold as "Osetra" (or "Ossetra," "Oscietra") caviar, although the latter term traditionally refers to eggs from the Caspian Sea's Russian sturgeon (*A. gueldenstaedtii*). Some companies describe their Amur sturgeon and hybrid products as farm-raised from China, East Asia, or just Asia, while others simply say the caviar is Chinese in origin without reference to wild or farmed status.

Researchers visiting nine Chicago stores and posing as buyers in 2017 and 2018 found several United States native and foreign species for sale, but none were confirmed to be Amur sturgeon, although some samples could not be identified (Harris and Shiraishi 2018, pp. 53). Some retailers did not meet CITES labeling and seal requirements (Harris and Shiraishi 2018, pp. 54) and legitimate CITES-endorsed labels and containers are believed to be resold on the black market to conceal transport of illegal caviar (van Uhm and Siegel 2016, pp. 81).

Following the 1998 CITES listing, there was a notable increase in Russia-to-China transport of caviar and meat (Vaisman and Fomenko 2006, pp. 24). However, no such trade specific to Amur sturgeon is documented in the CITES database, although there are two transactions totaling 400,050 live sturgeon eggs of unspecified species (CITES and UNEP-WCMC 2019). Thus most or all such transboundary trade in Amur sturgeon has been illegal. The exact volume of black market sturgeon trade is difficult to quantify, but over 1300 kg of Amur and kaluga sturgeon caviar was confiscated *en route* from Russia to China in 1999 (Vaisman and Fomenko 2006, pp. 24). Officers have also recovered fertilized eggs in transit from Russia to China, extremely likely destined for aquaculture facilities (Harris and Shiraishi 2018, pp. 40; Vaisman and Fomenko 2006, pp. 24). In winter, much of the sturgeon exported from Russia to China is smuggled by driving directly across the frozen river (Vaisman and Fomenko 2006, pp. 24).

Japan is a significant consumer of sturgeon products, with a growing trade in sturgeon-containing cosmetics there (Harris and Shiraish 2018, pp. 68). Much research is now ongoing regarding the chemical composition of Amur sturgeon tissues (including eggs and swim bladders) and their purported benefits to human skin (Wang et al. 2019; Zhang et al. 2016 & 2019). Poached Amur sturgeon products were continuously available in parts of Japan as of the mid-2000s, shipped there through the Russian port of Sovetskaya Gavan (Vaisman and Fomenko 2006, pp. 23). In 2016, Japanese customs officials seized 483 sturgeon products, 80% of which were cosmetics (Harris and Shiraishi 2018, pp. 59). South Korea is the primary exporter of sturgeon cosmetics (Harris and Shiraishi 2018, pp. 55), although it is not clear from available information which species are used and whether they are of farmed or wild origin.

Several European Union (EU) countries are also major buyers of sturgeon. Between 1998 and 2006, 3777 kg of Amur sturgeon caviar were imported into the EU (UNEP-WCMC 2008, pp. 31), representing 19% of the total reported export from China and Russia combined (Engler and Knapp 2008, Table 3). Between 2007 and 2015, Belgium alone imported almost 3000 kg of Amur sturgeon—mostly as caviar—and over 14,500 kg of kaluga-Amur sturgeon hybrid products (Musing et al. 2018, pp. 37). In Paris, France, farmed Amur sturgeon was also for sale in several markets in December 2017 (Harris and Shiraishi 2018, Table 28). There, most vendors told researchers acting as buyers that wild-sourced caviar is no longer available, although one said it could be obtained on the black market (Harris and Shiraishi 2018, pp. 45).

CITES and international trade 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, pp. 48). CITES regulates international trade in listed species through a system of permits and certificates that must be presented upon import/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) on *Conservation of and trade in sturgeons and paddlefish*];
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 and USFWS OLE March 13, 2008]
3. registration of caviar-production companies;
4. recommendation for countries to establish export quotas set as a result of a non-detriment finding by a 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) on *Management of nationally established export quotas*);
5. an exemption from CITES regulation for personal (non-commercial) import/export of 125g or less of sturgeon caviar (50 CFR 23.15; USFWS undated; CITES 2015, 2e).

Trade records suggest that China and Russia each exceeded their export quotas for Amur sturgeon at least once in the early 2000s (Harris and Shiraishi 2018, Table 3) and in 2000 and 2001, CITES Parties initiated the Significant Trade Review process for several sturgeon species, including Amur sturgeon, due to concern that trade in these species might not be conducted sustainably (Raymakers 2002, pp. 534). The review found that CITES was not being implemented suitably for Amur sturgeon and the CITES Animal Committee requested detailed information from China and Russia on the existing stocks, methods used for establishing annual catch and export quotas (including Russian test fishing), and conservation measures for the species (CITES 2001a, pp. 14–15 & 34–38). Replies from the Chinese CITES Management Authority (but not the Russian counterpart) were deemed satisfactory and stopped the CITES Standing Committee from recommending that importing countries stop accepting imports of the species (CITES 2001b, pp. 1–2).

Since 2011, no quotas for wild-caught Amur sturgeon have been reported to CITES, calling into question the legality of any international trade in wild specimens of the species (Harris and Shiraishi 2018, pp. 9–10). Since sturgeon were listed in CITES in 1998, there has been a near-complete shift in the reported provenance of internationally traded caviar; whereas nearly 100% was wild-sourced in 2000, 95% was from farmed fish in 2015 (CITES Trade database cited in

Harris and Shiraishi 2018, pp. 25). This switch to farmed sturgeon has occurred for Amur sturgeon, in particular, too, with almost all CITES-reported trade being sourced from farmed fish since 2008 (Fig. 3.5 and UNEP-WCMC 2008 pp. 31).

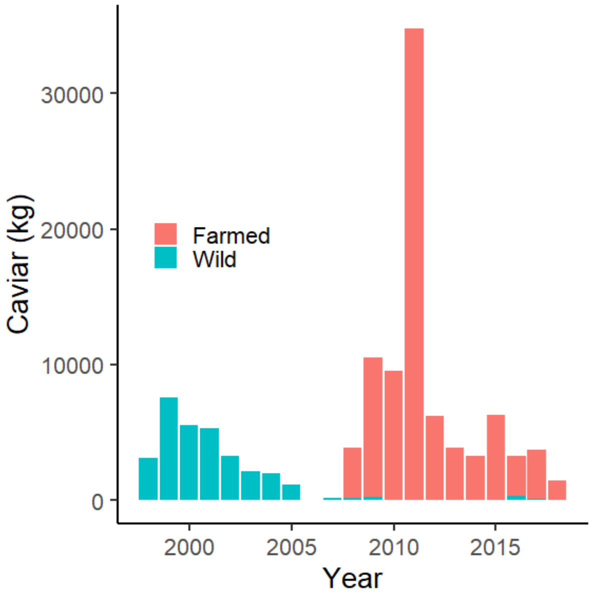

Figure 3.5—Volume of international trade in Amur sturgeon caviar by year and source, beginning in 1998 when all sturgeon were listed in the CITES appendices. Data are as reported to CITES by import and export countries and exclude 30 of 569 total records stemming from shipments of caviar produced before 1998, from wild-caught fish raised in farms, that were confiscated on import, or that had no known source information. Original data from CITES and UNEP-WCMC 2019.

While these trends are encouraging, they are not the last word on trade of wild Amur sturgeon. Russia is one of many countries that has stopped including caviar in its CITES annual reports, so the database is incomplete (UNEP-WCMC 2012, pp. 22). The considerable illicit trade in Amur sturgeon is still operating (Harris and Shiraishi 2018, pp. 9–12; Vaisman and Fomenko 2006, pp. 19–21).

In summary, there is abundant evidence that heavy fishing pressure has for several decades put severe pressure on Amur sturgeon populations. CITES regulations have not ended black market trade or the laundering of wild-caught fish and caviar into the legal market for farmed products, which is facilitated by organized crime and corrupt officials. CITES also does not regulate the actual harvesting of wild animals.

Dam construction (see also Table A2.2)
Around the world, dam construction hinders habitat connectivity for fish (Reid et al. 2019, pp. 856; Winemiller et al. 2016, pp.128–129), including for sturgeon in Russia and China (Zhuang et al. 2016, pp. 66; Wu et al. 2015, pp. 839–842; Gessner et al. 2010, not paginated). Dams along migration routes block sturgeon from reaching spawning grounds, can increase sediment and pollution loads, and raise water temperatures, thereby delaying spawning times (He et al. 2017, pp. 7; Kondrat'eva et al. 2013 pp. 133; Gessner et al. 2010, not paginated). Increased sediment concentrations limit sunlight that benefits egg development and can reduce the adhesion of sturgeon eggs to the substrate (Li et al. 2012, pp. 557).

Compared to other species (e.g., salmon) for which fish ladders and passageways have been successful mitigation measures, sturgeon are usually slower swimmers with larger bodies, and both fish elevators and fish ladders have been relatively ineffective for sturgeon (Billard and Lecointre 2001, pp. 380). For Amur sturgeon, fish passageways made to allow travel through or around dams must include resting pools between fast velocity runs and must be wider than the maximum tail-beat width during swimming (Cai et al. 2013, pp. 153).

The main stem of the Amur is one of the largest undammed rivers in the world, as of 2019 (GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502; Simonov and Dahmer 2008, pp. 185), but for at least 70 years, there have been repeated proposals to build dams there (Simonov and Markina 2010, not paginated). Proposed dams were not built at least partly due to soured China-Russia relations in the 1960s (Simonov 2016, not paginated), but more recently as many as six dams were proposed for construction on the main channel of the river (Simonov 2016, not paginated). However, these plans, too, were never fulfilled when in 2000 the Russian and Chinese delegations could not agree on specific design criteria (Simonov 2016, not paginated).

Going forward, the Russian state hydrological plan for the Amur region does not include development of hydropower dams on the river's main stem, and little regional demand exists for additional electrical capacity on the Russian side of the river (Simonov 2016, not paginated). Moreover, there was little public support for hydropower development in Russia, with protests scuttling the construction of a planned dam on the Shilka River, the Amur's main source, in 2012 (Simonov 2016, not paginated).

Figure 3.6—Locations for six proposed dams on the Upper and Middle Amur main stem and of six major dams existing on the Zeya, Bureya, Songhua, and Nen Rivers. Each of the proposed dams was included in the 2002 20-year plan for hydropower development in China. Proposed locations are reproduced from Simonov and Dahmer (2008, Figure 3.1). Existing locations are as in GRanD (2019, not paginated).

Proposals still exist for as many as many as 13 dams on the Amur (or Shilka, its source; Fig. 3.6; Simonov et al. 2019, Fig. 2). Some Russian water management agencies are now promoting flood control for property protection in the Amur floodplain and Chinese authorities and companies remain bullish on future hydropower development as the much larger human population on their side of the river demands electricity (Simonov 2016, not paginated). Environmental reviews conducted during the planning phase indicated that construction of the Khingansky-Taipinggou Dam still proposed for the Middle Amur would have severe hydrological impacts on the river, including the establishment of a complete barrier to migrating fish (Simonov and Egidarev 2018, pp. 9–10).

Until recently, prevailing economic and social conditions made it unlikely that Chinese and Russian counterparts will agree to advance such a project in the next several years (Simonov and Egidarev 2018, pp. 10). Indeed, none of the six main stem dams (all at Middle and Upper Amur locations; Fig. 7) listed by China's Ministry of Water Resources as planned future sites of hydropower development since 2003 have been built (Simonov 2016, not paginated). However, recently thawing China-Russia relations (Chen 2019, pp. 62–64) could allow dam approvals. Regardless, construction of any dam on the Lower Amur main stem would be catastrophic for Amur sturgeon by hindering or preventing connectivity (Simonov and Dahmer 2008, pp. 193–194).

While the Amur itself remains free-flowing, approximately 100 dams dot its tributaries (Simonov et al. 2019, pp. 4). Many of these are small and their impacts on Amur sturgeon are uncertain. They more likely than not prevent connectivity along stretches of several tributaries and have likely contributed to the species' decline. However, we do not know the degree of these impacts.

Some tributaries also have larger dams. The Songhua River, a major tributary in the lower section of the Middle Amur, is interrupted by the Baishan, Hongshi, and Xiao Fengman dams (GRanD 2019, not paginated; Lehner et al. 2011, pp. 494–502). These three are each large hydroelectric dams of approximately 150, 50, and 150m height and with upstream reservoirs of 85, 8, and 193 km^2, respectively.

Farther upstream, the Zeya and Bureya Rivers are interrupted by the Zeya and Bureya dams, built in 1975 and 2003, respectively (GRanD 2019, not paginated; Simonov et al. 2019, pp. 4; Lehner et al. 2011, pp. 494–502). These two large hydroelectric dams are 115 and 140 m high with reservoirs of 2235 and 586 km^2 (Lehner et al. 2011, pp. 494–502) and have the greatest ecological impacts of any of the dams in the Amur basin (Simonov and Dahmer 2008, pp. 191). The Zeya and Bureya dams block Amur sturgeon movement and destroyed downstream wetlands (Simonov and Dahmer 2008, pp. 192), contributing substantially to the extirpation of the species from these rivers (Koshelev et al. 2014a; pp. 1313 & 1316; Krykhtin and Svirskii 1997, pp. 237). Yet another dam downstream of the existing Bureya impoundment began operating in 2017 (Simonov et al. 2019, pp. 4) and will further limit the potential to restore sturgeon to the Bureya River. In addition, the Zeya and Bureya catchments are home to over 30 reservoirs storing heavily polluted wastewater and mining residues; failure of the smaller dams that contain these reservoirs poses a high risk (Simonov and Dahmer 2008, pp. 191).

Last among the major dams existing in the Amur watershed is the Nierji dam on the Nen River. This dam was built in 2006, after the Amur sturgeon was already extirpated from this tributary (Lehner et al. 2011 & GRanD 2019, not paginated), but would make restoration efforts there difficult.

Pollution (see also Table A2.3)

Chemical pollutants in the Amur environment

Pollution of the Amur basin has likely contributed to the decline of Amur sturgeon (Simonov and Dahmer 2008, pp. 47 & 212–236; Zhang 1985 cited in Zhuang et al. 2003, pp. 38). Extensive human settlements, agriculture, and industry—especially but not exclusively in China—all pollute the Amur and its tributaries with petrochemicals, heavy metals, and persistent organic pollutants such as polychlorinated biphenyls (PCBs)(Jiang et al. 2016, pp. 537; Meng et al. 2016, pp. 1– 5). In the late 1990s and early 2000s, pollution in the lower Amur was considered at an emergency level and mass fish kills were not uncommon (Erickson 2007, pp. 30; Jen 2003, pp. 3). Raw sewage, feces from domestic animals, pesticides including DDT, oil, industrial toxins from plastic, rubber, and paper manufacturing (Kondratyeva et al. 2012, pp. 186), and eutrophication (the process by which waters lose oxygen following extreme plant growth triggered by excessive nutrient inputs) due to fertilizer runoff all damaged the river ecosystem (Erickson 2007, pp. 30; Jen 2003, pp. 2–3).

Historically, the Songhua River in the Middle Amur has been the most contaminated tributary (Kondratyeva et al. 2012, pp. 185). Two large industrial accidents contaminated the Songhua (and eventually the Amur River downstream). In November 2005, an explosion at a petrochemical plant at Jilin City, China released around 100 metric tons of nitrobenzene, benzene, aniline, chloroform, chlorobenzene, and other chemicals into the Songhua (Kondratyeva et al 2012, pp. 186; The Guardian, Nov. 25, 2005). The spill eventually spread into a 100–150 km length of river that drifted nearly a 1000 km downstream. Concentrations of these chemicals were as high as 600 times the government-accepted levels (Kondratyeva et al 2012, pp. 186). Chemicals from the spill were later detected in fish tissues, including those of Amur sturgeon (Kondratyeva et al. 2012, pp. 187–189; Levshina et al. 2009, Table 1 & pp. 779) and fish were found with both internal and external morphological abnormalities, including heritable ones (Kondratyeva et al. 2012, pp. 189). Water column chemical concentrations declined to background levels within several months (Levshina et al. 2009, Fig. 2).

In July 2010, again at Jilin City, thousands of barrels of chemicals totaling over 500 metric tons were washed by flooding into the Songhua River. The barrels stored trimethyl chloride and methyl chloride, explosive and toxic chemicals (Agence-France Presse, July 29 2010). In this case, containment efforts and the integrity of the barrels may have prevented most damage, although there appears to have been less monitoring and follow-up than after the 2005 explosion (Agence-France Presse, July 29 2010).

Even where there has not been an acute release of toxic chemicals, industry along the Songhua has created serious pollution problems. Heavy metals leach into the river from nearby mines (Jen 2003, pp. 4) and accumulate along the Chinese bank of the Amur from the Songhua confluence to Komsomolsk-na-Amur (Kondrat'eva et al. 2013, pp. 36). Fish tissues have PCB concentrations up to 10,000 times those in the sediment (Li et al. 1989 cited in Meng et al. 2016, pp. 5). Songhua and Ussuri River pollution contaminates ice that forms annually on the Lower Amur, although ice at the northern (Russian) bank of the river usually remains clean (Kondratyeva and Zhukov 2013, pp. 44). Some Amur River fish are even said to smell of chemicals (Simonov and Dahmer 2008, pp. 225).

Untreated wastewater raises river nitrogen and phosphorus concentrations in the Middle Amur, with the potential to create low-oxygen dead zones through eutrophication (Simonov and Dahmer, pp. 220). In 2001, 100 million metric tons of wastewater containing 2500 metric tons of organic chemicals, 80 metric tons of oil products, over 1000 metric tons of nitrogenous waste, and 2.5 metric tons of phenols were discharged to the river from Blagoveschensk (Simonov and Dahmer 2008, pp. 2016). The same wastewater also carries microbial pollution; fish from the lower river are regularly found with bacterial counts 100 times the accepted level for human consumption (Simonov and Dahmer 2008, pp. 226); there is no indication that these infections are necessarily causing diseases in Amur sturgeon, though.

In the Upper Amur, including the Shilka, Amgun, and Argun Rivers, illegal gold mining causes sedimentation and turbidity, discouraging fish spawning (Pacific Environment 2016, not paginated; Egidarev and Simonov 2015, pp. 900, 906–907). Gold mines also impact about 3% of all river lengths in the Amur basin, although this figure rises to 10% in the Middle Amur and Selemdzha River (a Zeya tributary) region (Egidarev and Simonov 2015, pp. 902). The Zeya and Bureya catchments were also substantially polluted with mercury, cadmium, and lead as of 2005 (Kondrat'eva et al. 2013, pp. 131).

Amur sturgeon exposure and responses to chemical pollutants

The impacts of pollution on wild Amur sturgeon have not been well studied, but their life history and some laboratory studies indicate they are likely quite susceptible. Because Amur sturgeon live close to the bottom of rivers, seas, and lakes, 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, pp. 10; Kondrat'eva et al. 2013, pp. 129; Kocan et al. 1996, pp. 161).

Sturgeon are, at least at their early life stages, sensitive to polycyclic aromatic hydrocarbons (PAHs); one class of petrochemicals polluting the Amur (Kondratyeva and Stukova 2009, pp. 46; Bickham et al. 1998, pp. 514–515; Kocan et al. 1996, pp. 163). In one laboratory trial, 40% and 10% of Russian sturgeon were killed by exposure at 2.4 and 1.2 parts per thousand to PAH-contaminated sediments, respectively (Tabak et al. 2002, Table 3; Bickham 1998, pp. 514–515). We are not aware of field-based studies reporting tissue concentrations of these contaminants and their effects in wild sturgeon, so it is difficult to extrapolate these lab-based results to real-world impacts. Similarly, over 70% of shortnose sturgeon *A. brevirostrum* embryos and 20% of larva were killed on exposure to coal tar from river sediments (Kocan et al. 1996, pp. 163). We are not aware of any such exposure studies conducted on Amur sturgeon, but it is reasonable to expect similar levels of susceptibility to these closely related species; therefore, large numbers of Amur sturgeon hatchlings may be lost to pollution, although this is uncertain given the lack of quantitative data on the local and temporally varying concentrations of both petrochemicals and Amur sturgeon.

In a broad study of heavy metals found in Amur River fish, the single Amur sturgeon sampled contained copper, chromium, arsenic, and mercury (Jiang et al. 2016, pp. Table 2) and most individuals of other species were similarly contaminated, suggesting a greater sample size of Amur sturgeon may have found the same (Jiang et al. 2016, pp. 540 & Table 2). Methyl mercury in wild sturgeon suppresses sex hormones, reduces growth and body condition, alters hormonal concentrations, possibly depresses reproductive success, and can even cause direct mortality (Depew et al. 2012, Table 2; Webb et al. 2006, pp. 447–450).

The volume and extent of pollution, results of (limited) laboratory toxicity studies, and reports of large-scale fish kills in polluted river reaches strongly suggest Amur sturgeon viability has decreased due to pollution. However, comprehensive toxin concentration data from around the basin and knowledge of the concentration thresholds at which Amur sturgeon are affected are unavailable. Field-based demographic studies definitively linking population declines to pollution also do not exist, to our knowledge.

Future water quality in the Amur basin

The future trajectory of water quality in the Amur basin is uncertain, but possibly improving. Since 2000, construction of water treatment plants and better management of industrial waste have reduced the diversity and concentration of organic toxins in the Songhua River (Meng et al. 2016 pp. 4–5 & Table 1). Mercury concentrations in Amur River sediments declined since the 1990s, likely due to a Russian economic slowdown that limited industrial mercury releases (Kot et al. 2009, pp 133).

Along the Chinese bank of the Amur River, the human populations of most industrial cities are shrinking, as cost-efficient raw materials are exhausted and industry declines (Duhalde et al. 2019, not paginated). In turn, pollution may decrease (Osipov 2020, pers. comm.). A number of transboundary water quality monitoring efforts and ambitions to improve water quality were also agreed to following the 2005 Jilin petrochemical release (Chen 2019, pp. 62–64), but these treaties may lack the enforcement and remediation provisions needed to improve water quality.

Establishment of protected areas

Improving relations between China and Russia have led to the creation of several small protected areas along the banks of the Ussuri and Nongjiang Rivers (the latter is a smaller tributary in the Middle Amur region (Chen 2019, pp. 62 & 65). In addition to the Ussuri and Nongjiang River protected areas that were mentioned in the dam construction section above, a small number of protected areas safeguard the Amur River and its tributaries from dam construction. In 2014, China upgraded the Taipinggu Nature Reserve—along the banks of the site of the proposed Taipinggu Dam— to National Nature Reserve status (Simonov 2016, not paginated; China Daily/Asia News Network 2014; not paginated). Although little information is available about this 20,000 hectare protected area, the new status reduces the likelihood of future dam construction (Simonov 2016, not paginated; China Daily/Asia News Network 2014; not paginated).

In Russia, the Norsky Strict Nature Reserve was created in 1998 to protect the confluence of the Nora and Selemdzha rivers, small northern tributaries of the Amur, where the Dagmarskaya Dam was proposed (Simonov et al. 2019, pp. 10). The Verkhneamursky Wildlife Refuge was created in the Upper Amur in 2015 as the result of several years of lobbying and advocacy. It protects no fewer than five potential dam sites in the Shilka River (one of the Amur's two source tributaries) and the Upper Amur (Simonov et al. 2019, pp. 18; Rivers Without Boundaries, December 18, 2015). Although Amur sturgeon are extirpated there, stopping the construction of dams maintains the potential for sturgeon restoration and movements along the river.

Climate change (see also Table A2.4)
We are not aware of any explicit assessments of Amur sturgeon's vulnerability to climate change, and little information exists on the thermal tolerance of the species in the wild. However, climate change is not considered a major threat to the species (Osipov 2020, pers. comm.; Ruban and Qiwei 2010, not paginated) and may actually have limited positive effects in the short term.

Global climate models (Karger et al. 2018, not paginated; Karger et al. 2017, entire) indicate that mean annual air temperature between 2041 and 2060 for the Russian and Chinese second-order administrative areas bordering the Amur River are projected to warm by 2.1 ± 0.8 °C to 2.8 ± 1.4 °C depending on the future trajectory of global greenhouse gas emissions. See Appendix IV for details of these calculations and the models used. Between 1953 and 1995, the duration of extreme high temperatures in the region increased by 2 days per decade while that of extreme low temperatures decreased by 3 days per decade (Yu 2013a, Fig. 3). While water temperatures are very likely to rise along with air temperatures, we do not know exactly how this will take place; the degree of coupling depends in part on local water depths and water sources flowing into the Amur along its length. Further, we lack data on the present or future temperature of waters across the Amur basin.

As the climate warms, water temperatures in portions of the current Amur sturgeon range could eventually reach an upper thermal tolerance for the species. However, we do not know what the thermal maximum is for Amur sturgeon, or which aspect of thermal regimes (mean annual temperature, maximum daily temperature, etc.) they are most sensitive to. That said, there is no indication yet that forecast temperatures are approaching any limit. Spawning generally occurs in 15–20 °C water (Wei et al. 1997, pp. 245), and in captivity, eggs will hatch in water at least as warm as 24.4 °C (possibly higher; Zhuang et al. 2003, pp. 39). Juveniles have been reared at 26 °C (Dapeng et al. 2004, pp. 294). Nonetheless, other sturgeon species 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, pp. 1508; Hupfeld et al. 2015, pp. 1197–1200). Yangtze sturgeon (*A. sinensis*) spawn primarily between 15 and 20 °C, but are stressed above 23 °C (Chang et al. 2017, pp. 1449). Amur sturgeon may eventually suffer the same fate.

On the other hand, warmer water can speed the maturation of Amur sturgeon (Krykhtin and Svirskii 1997, pp. 237) and so may have short-term positive impacts on the species, but we cannot currently estimate their magnitude or know at what point increasing water temperature stops being beneficial. Warm waters can cause kaluga sturgeon to reproduce a year early (Krykhtin and Svirskii 1997, pp. 234–235); if true of Amur sturgeon, this may slightly slow their decline (or speed future recovery). Lake sturgeon (*A. fulvescens*) juveniles from cohorts that were larva in years with more rapid spring warming have higher relative survival than those that developed in slow-to-warm springs (Nilo et al. 1997, Fig. 2).

There is also some chance that warming may decrease the likelihood of cold-induced die-offs in Amur sturgeon. In 1983, a mass die-off of the species occurred at Boshnyakovo on Sakhalin

Island, south of the Amur estuary (Novomodny et al. 2004, pp. 20). Frigid, strong winds are thought to have blown highly saline water into the area, but a chemical spill is not ruled out (Novomodny et al. 2004, pp. 20; Krykhtin and Svirskii 1997, pp. 238). Without further information, it is difficult to gauge the exact risk to the species from similar threats in the future. However, warming temperatures may reduce any prior risk to the species from similar rare events.

We also do not know if increasing temperatures *per se* are the aspect of climate change to which Amur sturgeon are most sensitive. For instance, the Amur River and especially the adjacent Sea of Okhotsk are major sources of Pacific sea ice each winter (Denyer and Mooney 2019, not paginated). As the climate warms, ice generation and coverage are declining; between 1955 and 2014, the average annual duration of ice cover in the Amur basin decreased by 7 days per decade and the maximum ice thickness decreased by 17 cm (Vuglinsky and Valantin 2018, pp. 83; Ohshima et al. 2016, pp. 10–11). This potentially exposes Amur sturgeon to fishing pressure for a greater proportion of the year. Indeed, the combination of climate change with other threats can push a species to extinction, where it would otherwise survive the individual threats (Brook et al. 2008, pp. 457–459).

Captive reproduction for restocking

A small fraction of Amur sturgeon aquaculture is aimed at restocking wild populations, but these efforts are not yet sufficient to recover the species. One pair of experts estimated that at least 10–11 million Amur sturgeon juveniles need to be released into the Amur basin each year to recover the species' range and abundance (Krykhtin and Gorbach 1994 cited in Koshelev et al. 2014a, pp. 1316; but see *Scenario 2* in *Chapter 5*). The first Chinese-reared fish were released in 1988 and 1989 (Zhuang et al. 2002, pp. 361), with a few million juvenile Amur sturgeon released into the river by 1994 (Simonov and Dahmer 2008, pp. 130; Wei et al. 2004, pp. 330; Qiuzhi and Dajiang 1994, pp. 67). The Chinese hatchery at Qindeli halted all releases from 2005 to at least 2007 for lack of funding and to focus on commercial sale of sturgeon eggs (Simonov and Dahmer 2008, pp. 131). Only 6.2 million fish were released into the Amur River between 1995 and 2001 (Koshelev et al. 2014a, pp. 1313-1314), but as of 2014, three Russian hatcheries were rearing and releasing Amur sturgeon, including 2.85 million in 2011 (Koshelev et al. 2014a, pp. 1316).

The suggested volume of production and release (10–11 million juveniles per year) is not unattainable, though. China has a more robust Amur sturgeon aquaculture industry than Russia, raising over 60 million sturgeon (all species) each year between 2007 and 2009 (Wei et al. 2011, Fig. 5). By biomass, 15% (approximately 9 million fish) were Amur sturgeon, indicating that only a very slight change in composition of sturgeon species raised would be necessary (Wei et al. 2011, Fig. 2). However, 99% of the Amur sturgeon produced were sold for meat and caviar as of the early 2000s (Simonov and Dahmer 2008, pp. 131; Wei et al. 2004, pp. 330). In the Caspian Sea region, where several sturgeon species are threatened, tens-to-hundreds of millions of farmed sturgeon fry were released annually in the 1990s, despite much lower regional aquaculture capacity than exists today in the Amur region (Billard and Lecointre 2001, pp. 383; Bronzi et al. 2017, pp. 258). Whether Chinese policymakers reverse course and invest in significant reintroduction efforts in the coming decades in uncertain, but we believe it is unlikely in the next 5 years.

A further challenge for restoration efforts is to understand the success of released fish. We are not aware of any studies that have tracked the growth and/or reproductive success of Amur sturgeon released from fish farms. However, most fish are released as fry, weighing in the range of 1–5 g (~0.1 oz), and these small juveniles have very low survival rates (Koshelev et al. 2009 and Mikhailova 2004 cited in Koshelev et al. 2014a, pp. 1313–1316). Amur sturgeon at this size are around 30–45 days old (Koshelev et al. 2014a, pp. 1314; Zhuang et al. 1999 and Liu et al. 2000 cited in Zhuang et al. 2002, pp. 661) and studies of other sturgeon species indicate that no more than 1-in-2000 such fish reach 1 year of age, although survival rates are much higher thereafter (Table A5.1; Jaric and Gessner 2013, Table 1; Jager et al. 2001, Table 1). If hatcheries grew fish to a larger size before release, their survival and population recovery may improve (Koshelev et al. 2009 and Mikhailova 2004 cited in Koshelev et al. 2014a, pp. 1316; see also *Scenario 3* in Chapter 5 and Figs. 5.2 & 5.3 and Tables 5.3 & 5.4). A joint Russian-Chinese system of monitoring and research to inform better practices for release of hatchery-reared fish would also be useful (Novomodny et al. 2004, pp. 28).

Captive rearing for meat and caviar

Whereas captive cultivation can sometimes alleviate demand for wild individuals, the availability of farmed wildlife may also increase the demand for imperiled species by normalizing their purchase and/or ownership (Livingstone and Shepherd 2016, pp. 4; Kirkpatrick and Emerton 2010, pp. 657). Legal trade of Amur sturgeon also helps mask illegal fishing and sales (Novomodny et al. 2004, pp. 26). As of 2014, there were no requirements in China (where the majority of sturgeon farming occurs) that farmed sturgeon or caviar be certified as originating from captive broodstock, or even that the species be labeled correctly (Shen et al. 2014, pp. 1550). Some sturgeon aquaculture operations also threaten wild populations directly. Between 2007 and 2009, 12 million wild sturgeon (of all species) were caught and raised by Chinese farms (Wei et al. 2011, pp. 164), despite national policy that recommends aquaculture facilities use broodstock at least two generations removed from wild-caught fish and that requires permits for aquaculture (Harris and Shiraishi 2018, pp. 47).

China has rapidly become the global leader in sturgeon aquaculture, with a 1000% increase in volume farmed between 2000 and 2012 (Fig. 3.7; Bronzi et al. 2019, Fig. 1; Shen et al. 2014, pp. 1547-1549). The country produced 85% and 86% of all farmed sturgeon in 2012 and 2017 (Harris and Shiraishi 2018, pp. 13; Directorate-General for Maritime Affairs and Fisheries of the European Commission 2012, pp. 7) and the enormous growth of China's farmed caviar industry crashed United States prices by up to 60% between 2012 and 2018 (Reily 2019, not paginated).

During the 1990s, Amur sturgeon was the most commonly farmed sturgeon in China (Zhuang et al. 2002, pp. 659), but the species fell to the second spot by 2010–2012, during which time they made up 20% of production. Part of this drop may be due to difficulties with disease management in captivity (Gulyas and Li 2006 cited in Li et al. 2009, pp. 633). By 2016, Amur sturgeon made up only 10% of meat production and a negligible amount of farmed caviar, although its hybrids with kaluga and Siberian sturgeon constituted 36% and 13% of the meat and caviar farmed (Bronzi et al. 2019, pp. 260 & Fig. 11). Only Siberian sturgeon, a widespread species of northern Russia, was more commonly farmed (40% of meat globally in 2016; Bronzi et al. 260, pp 1547).

After China, Russia is the next-biggest sturgeon producer (Bronzi et al. 2019, Fig. 12) and a Russian government letter to the Service indicated in 2013 that 9 fish hatcheries were operating in Siberia. Amur sturgeon were mentioned as one species under cultivation (Russian Federal Institute of Fisheries and Oceanography 2013, pp. 2). As of 2016, one farm in Malaysia raised Amur sturgeon, primarily for sale to restaurants in Kuala Lumpur (Lim and Ng 2016, pp. 33–41). Only one aquaculture facility in Japan is registered for production of Amur sturgeon (Harris and Shiraishi 2018, pp. 55), and we are unaware of any United States or E.U. cultivation of the species.

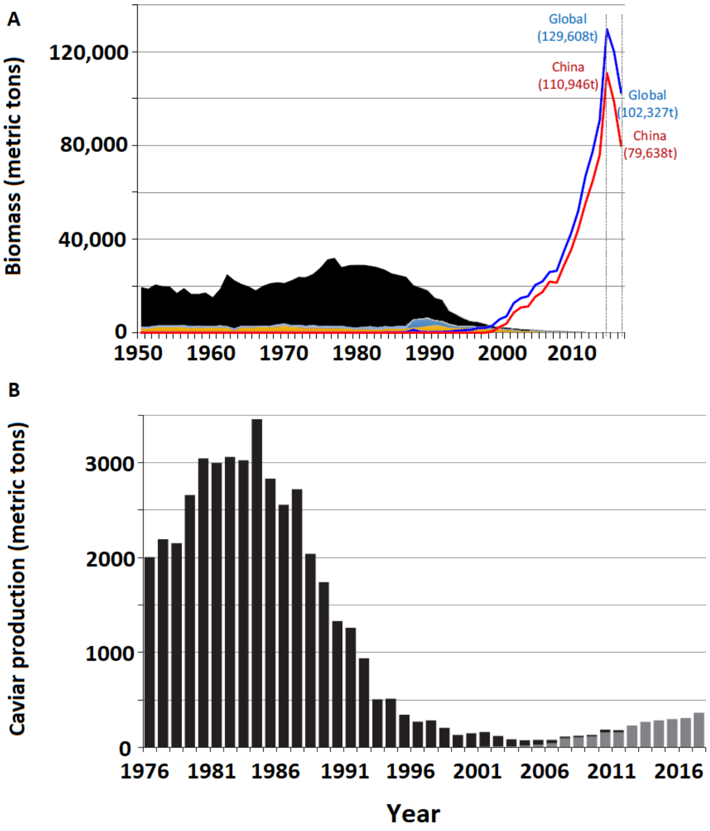

Figure 3.7—(A) Rapid growth of sturgeon meat production from farmed fish (blue line, global; red line, China) following the decline in trade of wild-caught sturgeon (shading; black = USSR/Russia, orange = Iran, blue = Kazakhstahn; other countries too small to see) and (B) the similar global trend for caviar production (black = wild-sourced; gray = farmed). Edited and reproduced from Figs. 1 & 8 of Bronzi et al. 2019. Data are incomplete due to lack of reporting from some smaller sturgeon-producing countries (e.g., North Korea and Moldova), but are still representative of global trends (Bronzi et al. 2019, pp. 258 & 260).

Hybridization (see also Table A2.5)

Because many hybrid fish are raised in the aquaculture industry, fish that escape from fish farms and interbreed with wild Amur sturgeon may contaminate the wild gene pool (Zhang et al. 2013, pp. 8). Amur sturgeon hybrids with Siberian and kaluga sturgeon are among the most-commonly farmed sturgeon in China (Bronzi et al. 2019, pp. 260 & Fig. 11 and see *Captive rearing for meat and caviar*, above). These hybrids can also contain genes from sterlet (*A. ruthenus*; a species of smaller sturgeon), likely due to poor farm management and careless crossbreeding (Zhang et al. 2013, pp. 8; Li et al. 2009, pp. 636).

Although very little information is available on the genetic structure of wild Amur sturgeon populations, **representation** of the species would be diminished if its genome were diluted by hybridization with escaped fish. Indeed, some Russian sturgeon (*A. gueldenstaedtii*) have hybridized with introduced Siberian sturgeon (*A. baerii*), leading to reduced morphological differentiation of Russian sturgeon (Ludwig 2006, pp. 6). From a fitness perspective, hybridization can erase locally adaptive features that evolved over evolutionary time, and from a conservation management perspective, muddled genomes make DNA-based identification of traded specimens more difficult (Ludwig 2006, pp. 6). Moreover, when kaluga and Amur sturgeon hybridize naturally, their offspring are heavily male-biased and may be sterile (Billard and Lecointre 2001, pp. 369; Krykhtin and Svirskii 1997, pp. 237).

We are not aware that wild Amur sturgeon have been documented hybridizing with fish escaped from aquaculture facilities yet (Osipov 2020, pers. comm.). However, the presence of over 1200 sturgeon farms across China (Bronzi et al. 2017, pp. 260) and confirmed escapes and releases of hybrid fish created in aquaculture suggests it is likely to occur soon, if it has not already (Boscari et al. 2017, pp. 250).

Disease and predation (see also Table A2.6)
Based on the available literature, we do not believe that predation or disease is contributing to the decline of wild Amur sturgeon populations.

CHAPTER 4—CURRENT CONDITION OF AMUR STURGEON

Extant distribution and abundance

Precise data on the abundance of Amur sturgeon are rare; however, the species is categorized as Critically Endangered on the Red List of Threatened Species maintained by the International Union for the Conservation of Nature (IUCN; Ruban and Qiwei, 2010 not paginated). This category is the most imperiled state IUCN assigns a species before considering it extinct in the wild. The Critically Endangered status was conferred to Amur sturgeon based on an estimated population decline of greater than 95% between 1960 and 2010 (Ruban and Qiwei 2010, not paginated). 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.

A series of Amur sturgeon surveys conducted between 2005 and 2011 (Table 4.1 and Koshelev et al. 2014a, pp. 1310–1314) are the most comprehensive, quantitative appraisal of the species we are aware of, for either contemporary or historic population estimates. Still, the sampling effort (the amount of time, number of samples, and area searched) is not well documented. Nonetheless, it is clear that Amur sturgeon has experienced intense and geographically extensive population declines as described in the IUCN status report (Koshelev et al. 2014a, pp. 1310–1316). Sizeable populations now exist only in the Amur estuary and Lower Amur analysis units, with the two upstream units largely depleted (Koshelev et al., 2014a, pp. 1313–1316). The remaining population exhibits a skewed sex ratio of 1 female per 2 males, very likely due to preferential poaching of females for caviar and use in aquaculture (Koshelev et al. 2014b, pp. 1127 & 1129; see Chapter 3 for detailed discussion of sturgeon harvesting).

As mentioned above, one expert estimate indicates a greater than 95% decline in the species' abundance between 1960 and 2010 (Ruban and Qiwei, 2010, not paginated). Even before 1960, however, population declines were great enough that Soviet authorities instituted strict fishery regulation (Vaisman and Fomenko 2006, pp. 11; see *Domestic fisheries regulation*). In other words, using a 1960 baseline underestimates actual historical declines in the species' abundance.

Table 4.1—*Summary of most-recent population estimates for four analysis units of* Amur sturgeon. *Sources are Koshelev et al. 2014a, pp. 1312–1316; Cai et al. 2013, pp. 150; Simonov and Dahmer 2008, pp. 129; Novomodny et al. 2004, pp. 18.*

Population	Most recent condition
Amur estuary	Extant; ~264,000 fish > 1y old; surveys 2005–2011
Lower river	Extant; ~25,000 fish > 1y old; higher density closer to the estuary
Middle river	Extirpated from the Songhua, Nen, Zeya, and Bureya Rivers and nearly so from the entire unit.
Upper river	Very likely extirpated, including from the Arugn and Shilka Rivers

Amur estuary

As of 2011, Amur sturgeon were most abundant in the Amur estuary (Koshelev et al. 2014, pp. 1312–1316). Relatively dense aggregations (~200 individuals per km^2) occurred along Cape Puir and Cape Uarke in the west of the Amur estuary, although the species was nearly absent from the eastern side of the estuary (Koshelev et al. 2014a, pp. 1312). Overall, the estuary contained approximately 264,000 fish >1 year old (Koshelev et al. 2014a, pp. 1316) estimated to be over 90% of all wild Amur sturgeon at the time (Koshelev et al. 2014a, pp. 1316).

Lower Amur

An estimated 26,000 Amur sturgeon >1 year old inhabited the lower river in 2011 (Koshelev et al. 2014a, pp. 1316). This indicates a large decline (Fig. 4.1), greater than 73% since the analysis unit was estimated in the early 1990s to have 95,000 fish >2 years old (Krykhtin and Gorbach 1994 cited in Koshelev et al. 2014a, pp. 1316; Krykhtin and Svirskii 1997, pp. 237). The estimated biomass of Amur sturgeon in the Lower Amur in 2011 (83.3 metric tons) was 6.3 times lower than just the amount harvested in 1891 (Koshelev et al. 2016, pp. 240). Very few sturgeon remain in the Ussuri River, a major Lower Amur tributary (Simonov and Dahmer 2008, pp. 129; Novomodny et al. 2004, pp. 18).

Middle Amur

Upstream of the Lower Amur, few Amur sturgeon remain. The 2005–2011 surveys found only a single individual in the Middle river region, fairly near to Khabarovsk (Koshelev et al. 2014a, pp. 1313). None were found in the Zeya and Bureya Rivers (Koshelev et al. 2014a; pp. 1313 & 1316). However, 65 Amur sturgeon were captured for a study in the lower-most portion of the Middle Amur between 2015 and 2017 (Li et al. 2019, pp. 822). None of these 65 fish were older than 10 years and only 5 were older than 6 years, indicating that few if any were of breeding age (Li et al., 2019 Table 2).

Amur sturgeon are very likely extirpated from the Songhua and Nen Rivers, tributaries south of the Middle Amur (Cai et al. 2013, pp. 150; Simonov and Dahmer 2008, pp. 129; Novomodny et al. 2004, pp. 18) and fishermen in the Zeya and Bureya basins said Amur sturgeon had been essentially absent since the 1980s (Koshelev et al. 2014a, pp. 1315).

Upper Amur

Surveys found no Amur sturgeon between 2005 and 2010 in the Upper Amur (Koshelev et al. 2014a; pp. 1313 & 1316). In fact, these populations were functionally extinct long before the Koshelev et al. (2014a) surveys (Krykhtin and Svirskii 1997, pp. 237). In the upper river, fishermen also reported that Amur sturgeon was nearly gone from the Shilka and Argun River drainages (the headwaters of the Amur) by the late 1970s (Koshelev et al. 2014a, pp. 1315).

Size and demography of extant Amur sturgeon

Fishery records document changing demographic and size class distributions in Amur sturgeon since the early 20th century. The average size of Amur sturgeon individuals has declined as the largest individuals have been fished out of the population. In the lower Amur River, the average size of fish caught between 2005 and 2011 [fork length: 74.8 ± 1.17 (1 standard error, SE) cm] was 17% smaller than in 1929 and 1930 (90.1 cm; Koshelev et al. 2014a, Table 5). Even in the Amur estuary, the current stronghold of the population, the size of fish caught declined by 48% over the same time period (Koshelev et al. 2014a, Table 5).

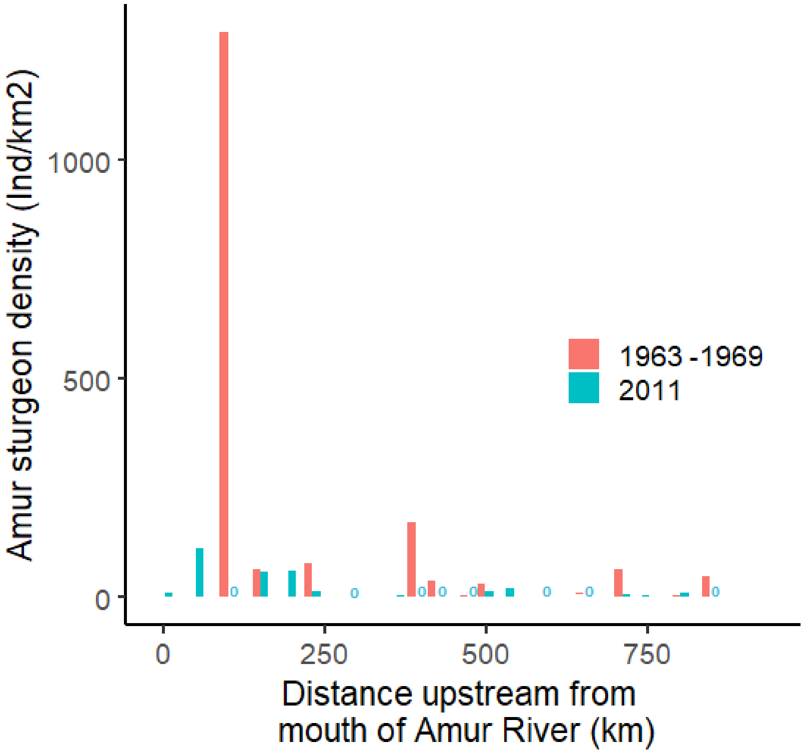

Figure 4.1—Current and historical Amur sturgeon density (individuals per km^2 of river) at sites in the Lower Amur. Red and blue bars indicate abundance for 1963–1969 and 2011, respectively. Bar position on the *x*-axis denotes distance from the mouth of the river (estuary begins at 0; upstream sites to the right). "0" indicates sites surveyed but with no fish captured in 2011. No surveys were conducted in the 1960s at sites without red bars. Data are from Table 2 of Koshelev et al. 2014a.

The proportion of Amur sturgeon females over 160 cm in length decreased from 23.3% to 13.8% comparing the period between the 1960s and 1990s with 2005–2009 (Koshelev et al 2014b, pp. 1129-1130). As a consequence, the average number of eggs carried and then laid by spawning females declined by approximately 20% (Koshelev et al 2014b, pp. 1129-1130).

Long-term declines in the size of captured fish are a common indicator of over-exploited fisheries (Shackell et al. 2010, Fig. 2; McClenachan 2009a pp. 636-643; McClenachan 2009b, pp 175-181). Indeed, the size of captured kaluga sturgeon—the related and sympatric species that is harvested by the same fisheries targeting Amur sturgeon—declined by 45% from 1929–1930 to 2005–2011 (Koshelev et al 2014a, Table 5).

Contemporary Amur sturgeon populations are also comprised of a lower proportion of reproductive-aged individuals than they were historically. Between 2006 and 2011, only 5.1% of Amur sturgeon caught in the river were reproductively mature, although 32.8% of fish caught in the estuary were mature (Koshelev et al. 2014a, pp. 1310). Whereas Chinese aquaculture operations in the 1950s–1970s could reliably collect pre-spawning individuals, in the middle Amur River, only a small number of locations (e.g., Qindeli and Fuyuan at the extreme downstream extent of the Middle River) had such individuals by the late 1990s (Zhuang et al. 2002, pp. 661) and few, if any, reproductive-age individuals exist in most of the Middle Amur today (Li et al. 2019, Table 2). Where reproductive populations are comprised of fewer and smaller females, fish species' **resilience** is reduced; fewer, smaller clutches will lead to a smaller number of offspring, and over time to decreasing adult abundance.

CHAPTER 5—PRESENT AND FUTURE OF AMUR STURGEON RESILIENCE, REDUNDANCY, AND REPRESENTATION

Current status of the species

We assessed the current and future status of Amur sturgeon in light of the species' demographic and habitat requirements for maintaining low-risk levels of **resilience**, **redundancy**, and **representation**. **Resilience** is a population-level metric (criteria in Table 2.2); we therefore only assessed its present levels for the three analysis units where Amur sturgeon are extant (Table 5.1).

We estimated the number of reproductive females in each of the three extant analysis units as follows. For the Amur Estuary, the total population of fish at least 1 year old is estimated to be 264,000 (Koshelev et al. 2014a, pp. 1310). Of this, 32.8% are mature (Koshelev et al. 2014a, pp. 1310) and one third are female (Koshelev et al. 2014b, pp. 1127). This gives an estimate of 28,860 reproductively mature females. For the Lower Amur, the total population of fish at least 1 year old is estimated to be 25,000 (Koshelev et al. 2014a, pp. 1310) with one third female (Koshelev et al. 2014a, pp. 1310) and just 5.1% mature. This yields an estimate of only 425 mature females. The Middle Amur unit is nearly extirpated.

All three extant units score low on survival to reproduce multiple times because the best available information indicates that continuing high fishing pressure removes 95% of spawning fish annually (note that fish spawn once in 3–4 years; Simonov and Dahmer 2008, pp. 47). Water quality and connectivity scores were derived from the above analyses of pollution and dams (and see Tables A2.2 and A2.3). Overall, the Amur Estuary has moderate **resilience**, while the Lower Amur has low **resilience** and the Middle Amur unit has very low **resilience** (Table 5.1).

Amur sturgeon **redundancy** is considerably reduced compared to its historic levels. One of four units (the Upper Amur) is extirpated, and the Middle Amur unit is on the brink of extirpation, too (Table 4.1). In addition, several major tributaries (e.g., the Zeya and Bureya) once home to Amur sturgeon, are no longer. Despite the species' low **redundancy**, we assess that its geographically dispersed nature, across a several-hundred km stretch of the Lower Amur and Estuary, means that complete extinction of the population due to a single catastrophic event is unlikely, at present.

Table 5.1—Current condition of extant Amur sturgeon populations in terms of population **resilience** criteria.

Resilience criteria	Amur Estuary	Lower Amur	Middle Amur
Number of reproductive females	~28,860 *4 points*	~425 *0 points*	Nearly extirpated. *0 points*
Water quality to support prey availability and sturgeon health	Receives water pollution from all upstream reaches, including the heavily polluted Songhua and Lower Amur. May impact sturgeon health and prey abundance. *2 points*	Heavy industrial presence and human population density; likely impacts sturgeon health and prey abundance. *1 point*	Songhua River includes the most polluted sections of the Amur Basin; Medium-sized cities Heihe and Blagoveschensk deposit sewage, industrial waste into the reach of the Amur; likely impact sturgeon health and prey abundance. *1 points*
Survival to reproduce multiple times	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	Few reproductive fish present and fishing pressure is likely still very high for any fish present. *1 point*
Connectivity between spawning and feeding grounds	No dams. Fish can move into the main stem of the river to reach spawning grounds. *3 points*	No known barriers to connectivity. *3 points*	Songhua, Nen, Zeya, and Bureya River dams prevent fish from reaching spawning sites. Main stem remains without obstructions. *2 points*
Total score:	**10 points; moderate**	**5 points; low**	**4 points; very low**

We have very little information about the contemporary population genetic structure of wild Amur sturgeon, making it difficult to fully assess the species' **representation**. The two existing color morphs in the Lower Amur very likely indicate some level of genetic (and possibly ecological) diversity remains (Krykhtin and Svirskii 1997, pp. 236). However, the adaptive significance, if any, and the genetic and ecological relationships between the two morphs are unclear (Ruban & Qiwei, 2010, not paginated). We can assess that the variety of ecological settings inhabited by Amur sturgeon is at least somewhat reduced in the last century as the geographic range of the species has contracted to primarily the Lower Amur and Amur Estuary. In turn, we expect that adaptive potential of the species is also lower than before, although we cannot quantify this at present.

Forecasting Amur sturgeon viability under alternative conservation futures

Based on our assessment of the current status, threats to, and conservation of Amur sturgeon, we conclude that continued overfishing, the possibility of increased restocking with farmed fish, and the potential of dam construction on the Amur main stem are three factors with great potential to affect the future viability of the species. We project Amur sturgeon viability in light of these three factors for 30 years from the present (2020–2050).

Most uncertainties in the future occurrence of overfishing, restocking of wild populations, and dam construction are driven by human factors such as, politics, economics, and cultural preferences. For instance, the international caviar market depends on demand for this luxury good, and desire for wild-sourced (as opposed to farmed) caviar remains high, at least for some consumers (Harris and Shiraishi 2018, pp. 10). We conclude it is likely that the market for this product will continue to be robust for at least 30 years in the absence of additional regulatory measures. Beyond that time period, it is harder to know how cultural shifts and awareness of sturgeon endangerment may affect demand.

Likewise, dam construction depends on political will, commercial interests, and public support (Simonov 2016, not paginated), all of which can shift substantially beyond the next few decades. No dam is expected on the main stem of the Amur in the immediate future, but proposed facilities could be built within the stated 30-year timeframe, especially as China-Russia relations are now improving. Thirty years also includes 2–3 generations of Amur sturgeon (9–14 years to sexual maturity) allowing impacts of changes to the species' threats and management to be born out in our simulations.

We forecast the **resiliency**, **redundancy**, and **representation** of Amur sturgeon under four alternative future scenarios. While not exhaustive of the management trajectories possible in the future, we developed plausible scenarios relevant to the future of overfishing, restocking of wild habitats, and construction of a major dam on the Amur main stem.

We projected future population sizes using modified Leslie matrix models (sometimes known as age-structured population models; Appendix V; Heppell et al. 2000, pp. 152). These models are based on the best available estimates of the initial population size (year 2020, derived from most recent published population estimates) and age distribution, which are then recomputed for successive annual time steps. The year-on-year calculations proceed according to best available estimates of Amur sturgeon demographic rates (survival, maturation, and reproductive output; Tables A5.2–A5.4) for each age class of fish. Where there was uncertainty in demographic parameters, we used conservative estimates, biasing our estimates of historical population sizes downwards and those of future population size upwards, if anything. This encourages scoring of depleted current and future populations as relatively abundant (healthy) compared to the historical condition (see Appendix V for details).

As one example of this conservative approach, we ran all the models using a wide range of possible annual juvenile survival rates (0.20–0.68; see Appendix V for details) derived from the literature. We present the results of the most optimistic of these models (juvenile survival = 0.68) in the SSA, but note that actual outcomes for Amur sturgeon may be less positive, if juvenile survival is not this high.

For all models, we report the range of projected population size for mature females (aged 9 and above) for the years 2040–2050 because of the cyclic nature of the population projections.

Population peaks occur in years with a pulse of juveniles that mature and are a product of the relatively high number of adults in the starting age distribution, time-to-maturity (9 years), and high mortality of adult fish. The peaks dampen as the population approaches a stable age distribution. A full description of the model structure and assumptions, and the specific literature-informed demographic parameters we used for each scenario and analysis unit are in Appendix V.

It is important to note that these models are mathematical representations of the expected trajectory of Amur sturgeon abundance and are produced purely in light of the species' demographic rates. They do not include potential effects of demographic or genetic stochasticity (another conservative characteristic of our models; Boyce 1977, entire; Vucetitch et al. 2000, entire), water pollution, connectivity, or other spatial or habitat quality factors, but are nonetheless valuable for comparing the effects of different recruitment, survival, and harvest rates on population growth. As such, Leslie matrix models are ideal for projecting the future condition of species like Amur sturgeon, whose foremost threat is harvest, and whose **resilience** is highly dependent on abundance of mature individuals. In the fourth scenario, we combine the demographic models with a qualitative analysis of the expected impacts to Amur sturgeon viability if a dam proposed for the main stem of the Amur were to be built.

Scenario 1—Status quo

The first scenario represents a continuation into the future of the *status quo*. We forecast the population trajectory of the three extant analysis units: the Amur Estuary, Lower Amur, and Middle Amur. Water quality, connectivity, and other threats and conservation measures, including continued stocking at current rates, were considered steady at current levels.

Population size is forecast to decline in all three analysis units if the current harvesting rate continues (Fig. 5.1; Tables 6.2, A5.1–A5.4). As a result, **resilience** of the Estuary unit may decline slightly from an upper-moderate level (10 points) to a moderate one (8–10 points) and the Lower Amur's **resilience** is projected to become very low. The Middle Amur is forecast to remain of very low **resilience** in 2050.

Redundancy of Amur sturgeon populations would remain steady in this scenario because no analysis unit is projected to be completely extirpated. However, the very low projected population size in the Lower and especially Middle Amur suggests stochastic events impacting these units could cause extirpation, with the likelihood of this result increasing closer to 2050. In addition, in the even that our conservative parameterization of the model (e.g., annual juvenile survival rate = 0.68 and a low-end estimate for female age at first reproduction = 9 years) is overly optimistic, we may be underestimating future declines. If this is the case, we would expect these units may be extirpated, and for **redundancy** to decrease beyond its already low state.

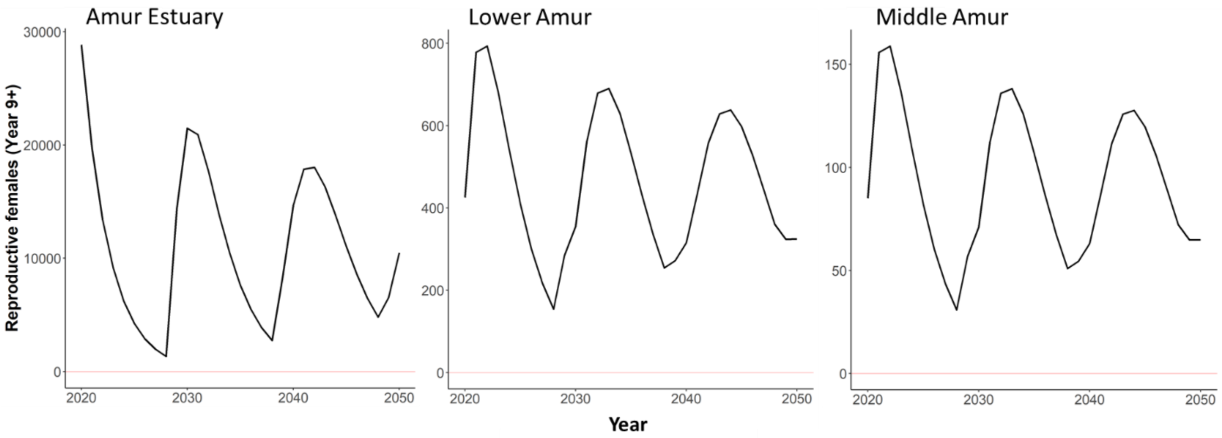

Figure 5.1—Population projections for mature females (age 9 and up) between 2020 and 2050 under the *status quo* (Scenario 1) future for each of the three extant analysis units. Note the different y-axis scales. Red lines at 0.

Representation would likely decline in this scenario as genetic diversity is lost with shrinking population size. Moreover, any hybridization of wild fish with escaped aquaculture fish would dilute the wild gene pool, further diminishing **representation**. This latter point is true of all future scenarios.

Because there is uncertainty in the exact current (and future) rate of harvest, we also conducted a sensitivity analysis for this first future scenario. Even if we double mature female survival (using 90% annual mortality of spawning fish = 10% annual survival instead of the best available estimate of 95% annual mortality of spawning fish = 5% annual survival; Simonov and Dahmer 2008, pp. 47), all three extant analysis units' populations are projected to decline (Fig. A5.1 and Table A5.5). When coupled with our already high-end estimates for survival of fish in all immature age classes, this further indicates that even using conservative demographic parameters, Amur sturgeon **resilience** will very likely continue to decline—and certainly not improve—without additional, effective conservation measures.

Table 5.2—Resilience in 2050 of extant analysis units under a *status quo* future scenario

Resilience criteria	Amur Estuary	Lower Amur	Middle Amur
Number of reproductive females	4802–18,023 *2–4 points*	316–638 *0 points*	63–128 *0 points*
Water quality to support prey availability and sturgeon health	Receives water pollution from all upstream reaches, including the heavily polluted Songhua and Lower Amur. May impact sturgeon health and prey abundance. *2 points*	Heavy industrial presence and human population density; likely impacts sturgeon health and prey abundance. *1 point*	Songhua River includes the most polluted sections of the Amur Basin; Medium-sized cities Heihe and Blagoveschensk deposit sewage, industrial waste into the reach of the Amur; likely impact sturgeon health and prey abundance. *1 points*
Survival and growth of females to reproduce with high fecundity	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	Few reproductive fish are found. *1 point*
Connectivity between spawning and feeding grounds	No dams. Fish can move into the main stem of the river to reach spawning grounds. *3 points*	*No known barriers to connectivity.* *3 points*	Songhua, Nen, Zeya, and Bureya River dams prevent fish from reaching spawning sites. Main stem remains without obstructions. *2 points*
Total score	**8–10 points; moderate**	**5 points; low**	**4 points; very low (< 200 mature females)**

Orange text indicates a decrease in the resilience from the present; Blue text indicates an improvement; Black text indicates no change.

Scenario 2—Increased restocking with fry

The second scenario represents a future in which the considerable aquaculture capacity in the Amur region is partially redirected to help restore wild populations. In recent years, less than 1% of sturgeon produced in China were released into natural habitats (Simonov and Dahmer 2008, pp. 131; Wei et al. 2004, pp. 330). Very roughly, this amounts to 600,000 sturgeon per year between 2007 and 2009 (Wei et al. 2011, Fig. 5). In contrast, at least 10–11 million fish reintroduced each year has been suggested as the level necessary for rehabilitation of the species' abundance and range (Krykhtin and Gorbach 1994 cited in Koshelev et al. 2014a, pp. 1316), although it is not clear how this number was determined.

To date, most fish used in restocking have been very young fry, around 30 days old (see above, *Captive rearing for meat and caviar*). As such, we built models for each of the four analysis units simulating the addition of 2.5 million age zero fish (totaling the recommended range-wide 10 million) to each analysis unit annually between 2020 and 2050. All other parameters were the same as in the Scenario 1 *status quo* models. As in Scenario 1, we assumed fishing pressure and other threats to and conservation actions for Amur sturgeon would remain consistent with our best available understanding of the current condition. The Upper Amur model was built starting with a completely extirpated population.

Even with annual restocking of fry, the Estuary and Lower Amur populations are projected to decline by 2050 (Fig. 5.2) compared to their current condition. In fact, the projected population sizes and **resiliency** for this scenario (Table 5.3) are nearly identical to those in the *status quo* Scenario 1. This is because of the very high mortality rate for fry; only about 1 in 2000 survive the first year (Jaric and Gessner 2013, Table 1), and little better than 1 in 100,000 (the compound probability of survival to year 9) survive to reproduce. The Middle Amur population is projected to begin growing slightly by about 2030, but only after an initial decline, and it would still have fewer than 200 mature reproductive females by 2050 (Fig. 5.2).

Our models predict that by 2050, fry restocking could allow the currently extirpated Upper Amur unit to support a very small breeding population. However, the population is projected to be so small (fewer than 90 breeding females; very low **resilience**) that we question whether it would be viable. Nonetheless, **resilience** of the Upper Amur unit may be considered to increase very slightly under Scenario 2. The Middle and Lower Amur units are also projected to have critically low abundance of reproductive females, and consequently are classified as having very low **resilience**, as well. Here it is worth mentioning again that the model does not account for constraints inherent to small populations such as Allee effects, inbreeding depression (Mills 2013, pp. 135–139), and genetic bottlenecks (Marranca et al. 2015, pp. 457; Ennen et al. 2011, pp. 203 & 208; Mayr 1954, pp. 157–180).

If we do consider the Upper Amur unit extant by 2050, then **redundancy** of Amur sturgeon is projected to increase under Scenario 2 because the number of extant analysis units would have increased from 3 to 4. However, we expect that **representation** would decline under Scenario 2 because the population size in the two most robust analysis units (the Estuary and Lower Amur) would decline precipitously, likely reducing the genetic diversity and adaptive potential of the species as a whole (Lande and Barrowclough 1987, pp. 87).

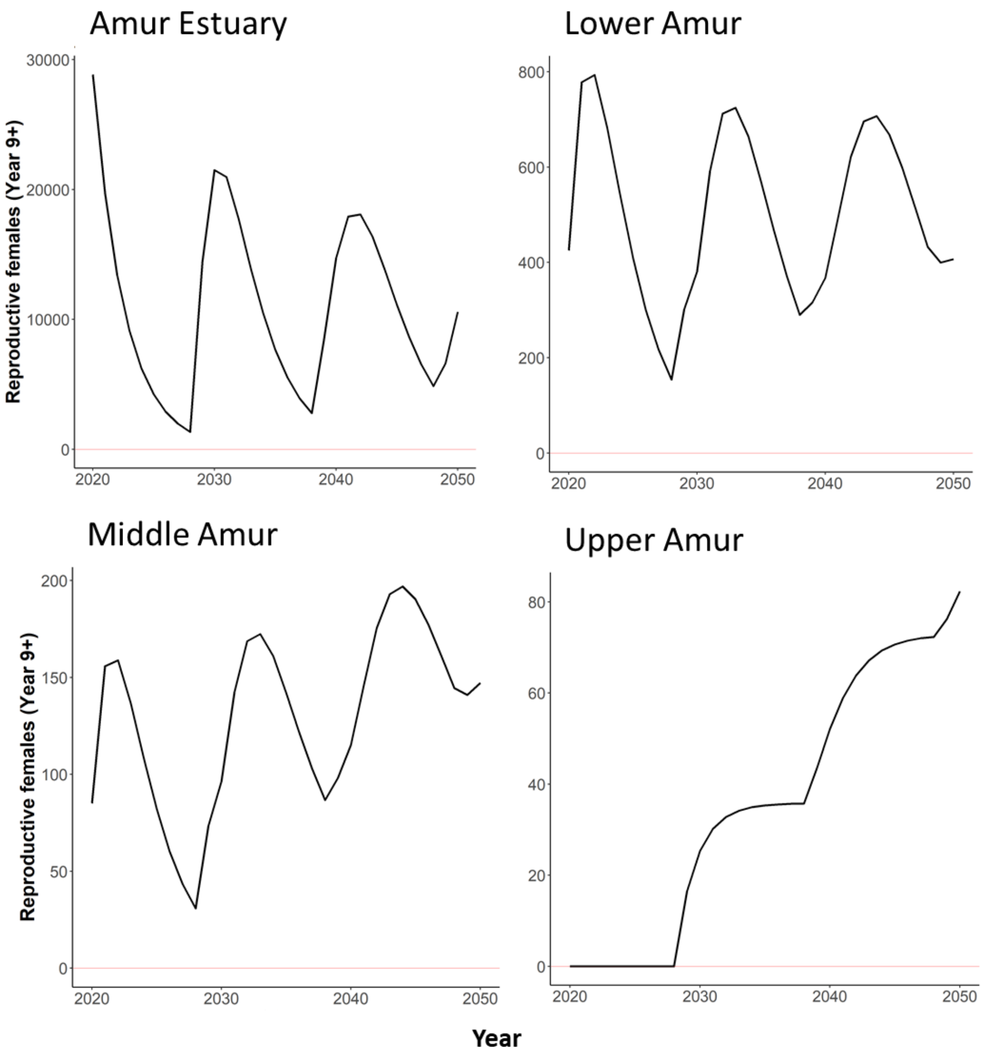

Figure 5.2—Population projections for mature females (age 9 and up) between 2020 and 2050 with increased restocking of fry (Scenario 2) for each of the four analysis units. Note the different y-axis scales. Red lines at 0.

Table 5.3—Resilience in 2050 of extant analysis units with annual restocking of fry

Criteria	Amur Estuary	Lower Amur	Middle Amur	Upper Amur
Number of reproductive females	4874–18088 *2–4 points*	368–707 *0 points*	115–197 *0 points*	52–82 0 points
Water quality to support prey availability and sturgeon health	Receives water pollution from all upstream reaches, including the heavily polluted Songhua and Lower Amur. May impact sturgeon health and prey abundance. *2 points*	Heavy industrial presence and human population density; likely impacts sturgeon health and prey abundance. *1 point*	Songhua River includes the most polluted sections of the Amur Basin; Medium-sized cities Heihe and Blagoveschensk deposit sewage, industrial waste into the reach of the Amur; likely impact sturgeon health and prey abundance. *1 points*	Sturgeon and prey health and abundance may be impacted by pollution, but the abundance of industry and human settlement is lower in this region than downstream. *2 points*
Survival and growth of females to reproduce with high fecundity	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	Given reports of possible ongoing efforts to harvest of kaluga and Amur sturgeon illegally, we expect high fishing pressure would exist for any re-established population. *1 point*
Connectivity between spawning and feeding grounds	No dams. Fish can move into the main stem of the river to reach spawning grounds. *3 points*	No known barriers to connectivity. *3 points*	Songhua, Nen, Zeya, and Bureya River dams prevent fish from reaching spawning sites. Main stem remains without obstructions. *2 points*	No known barriers to connectivity. 3 points
Total score	**8–10 points; moderate**	**5 points; low (< 200 mature females)**	**4 points; very low (< 200 mature females)**	**6 points; very low (< 200 mature females)**

Orange text indicates a decrease in the resilience from the present; Blue text indicates an improvement; Black text indicates no change.

Scenario 3—Increased restocking with year-old fish

The third scenario represents a future in which Amur sturgeon are farmed until one year of age before use in restocking. The best available demographic data indicates that annual survival of pre-reproductive sturgeon greater than 1 year old (1–9 years old for Amur sturgeon in our models) is as much as 1300 times the rate of survival for fish in their first year. Thus, introduction of many fewer 1-year-old fish than fry should be needed to recover Amur sturgeon. Given that aquaculture facilities regularly raise fish to maturity for breeding, they should already be capable of raising fish for a full year after hatching.

In this scenario, we built models for all four analysis units simulating the annual addition of 125,000 year-old fish (62,500 females) to each analysis unit (5% the number of fry restocked in Scenario 2). Again, all other demographic parameters were the same as in Scenario 1 and Scenario 2 and we assumed fishing pressure and other threats to and conservation actions for Amur sturgeon would remain consistent with our best available understanding of the current condition. The Upper Amur model was started from a completely extirpated population.

Our projections indicate that using year-old fish for restocking would be considerably more effective for recovering Amur sturgeon than would restocking with fry. By 2050, the **resilience** of the Lower and Upper Amur units would increase to moderate levels (Table 5.4). Although the population size in the Middle Amur unit would grow to several thousand mature females—similar in size to the Lower and Upper Amur—**resilience** in this unit would still be low because of dams and pollution. Amur sturgeon **resilience** in the Estuary is projected to remain at a moderate level after a less-intense decline than in the previous two scenarios. The population in the Estuary unit is also projected to begin growing slowly by about 2030 (Fig. 5.3).

The **redundancy** of Amur sturgeon populations is projected to increase under Scenario 3 because the number of extant analysis units would increase from 3 to 4, buffering the species from total extinction in the event of a stochastic or catastrophic event that impacted a subset of the analysis units. The impact on Amur sturgeon **representation** of restocking with 1-year-old fish is uncertain. On the one hand, the relatively large current population in the Estuary is projected to decline in size, which would likely mean loss of some genetic diversity. However, the geographic expansion of the species to again include the Upper Amur unit may mean that a wider range of ecological settings is inhabited by 2050, encouraging the evolution of genetically distinct sub-populations with variable adaptive potential.

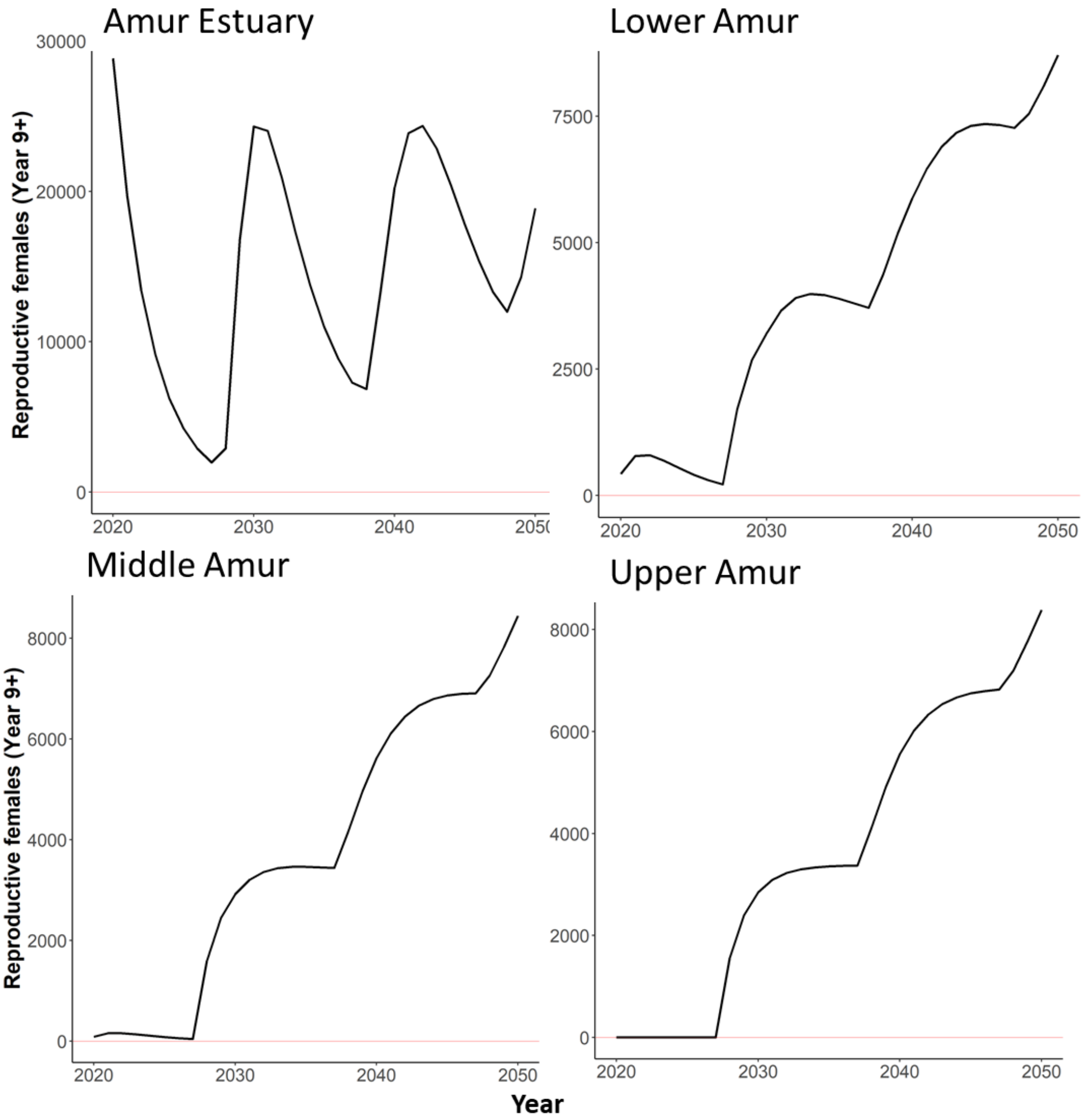

Figure 5.3—Population projections for mature females (age 9 and up) between 2020 and 2050 with increased restocking of 1-year-old fish (Scenario 3) for each of the four analysis units. Note the different y-axis scales. Red lines at 0.

Table 5.4—Resilience in 2050 of extant analysis units with annual restocking of 1-year-old fish

Resilience criteria	Amur Estuary	Lower Amur	Middle Amur	Upper Amur
Number of reproductive females	11,992–24,360 *4 points*	5873–8709 *2 points*	5620–8449 *2 points*	5557–8384 *2 points*
Water quality to support prey availability and sturgeon health	Receives water pollution from all upstream reaches, including the heavily polluted Songhua and Lower Amur. May impact sturgeon health and prey abundance. *2 points*	Heavy industrial presence and human population density; likely impacts sturgeon health and prey abundance. *1 point*	Songhua River includes the most polluted sections of the Amur Basin; Medium-sized cities Heihe and Blagoveschensk deposit sewage, industrial waste into the reach of the Amur; likely impact sturgeon health and prey abundance. *1 points*	Sturgeon and prey health and abundance may be impacted by pollution, but the abundance of industry and human settlement is lower in this region than downstream. 2 points
Survival and growth of females to reproduce with high fecundity	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	Given reports of possible ongoing efforts to harvest kaluga and Amur sturgeon illegally, we expect high fishing pressure would exist for any re-established population. *1 point*
Connectivity between spawning and feeding grounds	No dams. Fish can move into the main stem of the river to reach spawning grounds. *3 points*	No known barriers to connectivity. *3 points*	Songhua, Nen, Zeya, and Bureya River dams prevent fish from reaching spawning sites. Main stem remains without obstructions. *2 points*	No known barriers to connectivity. 3 points
Total score	**10 points; moderate**	**7 points; moderate**	**6 points; low**	**8 points; moderate**
Orange text indicates a decrease in the resilience from the present; Blue text indicates an improvement; Black text indicates no change.				

Scenario 4—Construction of the Khingansky-Taipinggou Dam
In the fourth scenario, we considered the potential impacts to Amur sturgeon of the construction of the Khingansky-Taipinggou Dam, one of several proposed Amur main stem dams (Simonov and Egidarev 2018, pp. 9–10). For over a decade, the dam has been proposed for siting on a north-south stretch of the Amur main stem about 150 km (river length) upstream of the Songhua confluence in the lower Middle Amur (Fig. 3.6; Simonov and Dahmer 2008, pp. 197). Diplomatic disagreements have so far prevented the dam's construction (see *Dam Construction* in Chapter 4), and a nature reserve on the Chinese bank reduces the likelihood that the dam will be built in the future (Simonov 2016, not paginated; China Daily/Asia News Network 2014; not paginated). However, recent improvements in China-Russia relations (Chen 2019, pp. 62–64) may eventually allow dam approval. Hanergy, a private Chinese energy company revived the proposal to construct the dam in 2016 and gained support from the Russian Ministry for Development of the Far East, an agency some say has a history of corruption (Simonov 2017, pp. 49).

The Khingansky-Taipinggou is considered the proposed dam with the greatest potential to harm the Amur environment (Simonov and Egidarev 2018, pp. 9–10). For Amur sturgeon, in particular, its proposed location sits in the midst of three major spawning grounds in Luobei county—where the dam site is—and just up- and down-stream, in Xunke and Tongjiang counties (Wei et al. 1997, pp. 245). The dam would create a near-complete barrier to connectivity among these areas.

Amur sturgeon more likely than not spawn primarily within the same river regions (Lower, Middle, Upper) in which they otherwise live (Novomodny et al. 2004, pp. 18; Ruban and Qiwei 2010, not paginated). However, a few migrations greater than 500 km in length may occur, with some estuary fish spawning in the river and traveling even 1000 km or more (Novomodny et al. 2004, pp. 18).

The Khingansky-Taipinggou dam site is greater than 1000 km from the Estuary, so we assumed that Estuary fish are unlikely to be impacted by the dam. The location is less than 500 km from the upstream limit of the Lower River, though, so we believe that Lower Amur sturgeon are more likely than not to be impacted. Therefore, we assigned a range of possible connectivity scores to the Lower Amur unit but did not alter the Estuary's score for this **resilience** criterion. The other three **resilience** criteria (mature female abundance, water quality, and survival to reproduce) are kept at levels identical to those resulting from the Scenario 1 *status quo* models, and we again did not consider the currently extirpated Upper Amur unit.

The Khingansky-Taipinggou dam would create a near-complete barrier to connectivity for Middle Amur sturgeon in what may historically have been the most significant breeding grounds for the species (Novomodny et al. 2004, pp. 18; Simonov & Dahmer 2008, pp. 191–194; Ruban and Qiwei 2010, not paginated; Krykhtin and Svirskii 1997, pp. 237). The Scenario 1 models project that this unit would have just 63–128 mature reproductive females by 2050, but the models do not account for decreased connectivity. When combined with the impacts of a major dam, we expect that this unit would likely be extirpated (Table 5.5).

Resilience in the Lower Amur is presently low, but population declines and possible loss of connectivity due to the dam's construction may cause the unit to have very low **resilience** in this scenario (Table 5.5). We believe the Lower Amur population is unlikely to be extirpated in this scenario, but there is high uncertainty in how the Khingansky-Taipinggou dam would affect this unit's fish. Amur Estuary **resilience** would remain at a moderate level , in line with the limited population declines projected in Scenario 1.

Table 5.5—Resilience in 2050 of extant analysis units following dam construction at Khingansky-Taipinggou

Resilience criteria	Amur Estuary	Lower Amur	Middle Amur
Number of reproductive females	4802–18,023 *2–4 points*	316–638 *0 points*	63–128 *0 points*
Water quality to support prey availability and sturgeon health	Receives water pollution from all upstream reaches, including the heavily polluted Songhua and Lower Amur. May impact sturgeon health and prey abundance. *2 points*	Heavy industrial presence and human population density; likely impacts sturgeon health and prey abundance. *1 point*	Songhua River includes the most polluted sections of the Amur Basin; Medium-sized cities Heihe and Blagoveschensk deposit sewage, industrial waste into the reach of the Amur; likely impact sturgeon health and prey abundance. *1 points*
Survival and growth of females to reproduce with high fecundity	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	Few reproductive fish are found. High fishing pressure. Estimated 95% of spawning fish captured annually. *1 point*
Connectivity between spawning and feeding grounds	No dams. Fish can move into the main stem of the river to reach spawning grounds. *3 points*	The Khingansky-Taipinggou Dam may or may not prevent fish from reaching spawning grounds; uncertain if Lower River fish migrate to sites that would be impacted. *2–3 points*	The Khingansky-Taipinggou Dam would create a complete barrier to connectivity in the heart of this unit and three major spawning grounds. Songhua, Nen, Zeya, and Bureya River dams still prevent fish from spawning there. *1 point*
Total score	**8–10 points; low-to-moderate**	**4–5 points; low–very low**	**Extirpated. We consider the very low population size and complete loss of connectivity very likely to cause extirpation of this unit.**
Orange text indicates a decrease in the metric from the present; Blue text indicates an improvement; Black text indicates no change.			

With extirpation of the Middle Amur unit, the **redundancy** of Amur sturgeon populations would decrease under Scenario 4. As for Scenario 1, we expect that **representation** would likely decline in this scenario as genetic diversity is lost to the shrinking population.

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APPENDIX I—CALIBRATION OF LIKELIHOOD TERMINOLOGY.

Likelihood Terminology	Likelihood of the occurrence/ outcome
Virtually certain	> 99% probability
Extremely likely	95–99% probability
Very likely	90–95% probability
Likely	66–89% probability
More likely than not	50–65% probability
As likely as not	About 50% probability
Unlikely	< 50% probability

APPENDIX II—CAUSE AND EFFECT TABLES FOR 6 STRESSORS

Table A2.1—Causes and effects of overfishing on Amur sturgeon

Overfishing			
	Analysis	Confidence	Supporting Information
SOURCE(S)	Caviar and meat trade (1).	High	1. Vaisman and Fomenko 2006, pp. 11
- Activity(ies)	Direct harvest of fish for caviar and meat; also live-capture for use as broodstock in aquaculture (1, 2). Illegal harvest and commercial sale is tied to corruption and organized crime in Russia (3, 4).	High	1. Vaisman and Fomenko 2006, pp. 11; 2. Vaisman and Fomenko 2006, pp. 24. 3. Vaisman and Fomenko 2006, pp. 19; 4. Liddick 2014 cited in Harris and Shiraishi 2018, pp. 14.
STRESSOR(S)	Direct mortality and/or removal of live fish from the wild population (1–4).	High	1. Vaisman and Fomenko 2006, pp. 11; 2. Vaisman and Fomenko 2006, pp. 24. 3. Vaisman and Fomenko 2006, pp. 19; 4. Liddick 2014 cited in Harris and Shiraishi 2018, pp. 14.
- Affected Resource(s)	Females less-often reach large size, reducing average fecundity and overall population size (5, 6).	High	5. Koshelev et al. 2014a, Table 5; 6. Koshelev et al. 2014b, 1129-1130.
- Exposure of Stressor(s)	Year-round and across the species' range, but possibly lower in the Estuary than in rivers (7).	Moderate	7. Koshelev et al. 2016, pp. 238
- Immediacy of Stressor(s)	> 100 years past and continuing (8).	High	8. Harris and Shiraishi 2018, pp. 23-30 & Annex II.
Changes in Resource(s)	Direct mortality and/or removal of live fish from the wild population.	High	1. Vaisman and Fomenko 2006, pp. 11; 2. Vaisman and Fomenko 2006, pp. 24. 3. Vaisman and Fomenko 2006, pp. 19; 4. Liddick 2014 cited in Harris and Shiraishi 2018, pp. 14.
Response to Stressors: - INDIVIDUALS	Direct mortality and/or removal of live fish from the wild population.	High	1. Vaisman and Fomenko 2006, pp. 11; 2. Vaisman and Fomenko 2006, pp. 24. 3. Vaisman and Fomenko

			2006, pp. 19; 4. Liddick 2014 cited in Harris and Shiraishi 2018, pp. 14.
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Although there is uncertainty in the exact number of fish remaining, the total population was estimated to be 95% lower in 2010 than in 1960, primarily due to overfishing (9). In addition, the population was very likely already somewhat depleted in 1960, judging by historical fisheries landing records (10).	High	9. Ruban and Qiwei 2010, not paginated; 10. Vaisman and Fomenko 2006, Table 3-6.
- GEOGRAPHIC SCOPE	Historically, the entire range of the species; now may be restricted to the lower Amur and estuary; it is uncertain whether fishermen in the Middle Amur still try to catch the very few fish remaining there (11). While much of the caviar and meat is consumed in Russia (12), there is a robust international market for caviar, as well (13-15).	Moderate	11. Harrish and Shiraishi 2018, pp. 46; 12. Vaisman and Fomenko 2006, pp. 20; 13. Nellemann et al. 2014, pp. 43; 14. Harris and Shiraishi 2018, pp. 26; 15. CITES and UNEP-WCMC 2019.
- MAGNITUDE	Overfishing is the main cause of the species decline.	High	9. Ruban and Qiwei 2010, not paginated; 16. Koshelev et al. 2014a, pp. 1310-1318.
SUMMARY	**Overfishing is the primary factor in the population crash of Amur sturgeon; there is continuing pressure from the ongoing caviar and meat trade.**	High	

Table A2.2—Causes and effects of dam construction on Amur sturgeon

Dams			
	Analysis	Confidence	Supporting Information
SOURCE(S)	Expansion of hydropower capacity and flood control (1).	High	1. Simonov and Dahmer 2008, pp. 178-202.
- Activity(ies)	Construction of dams (1, 2).	High	1. Simonov and Dahmer 2008, pp. 178-202; 2. Simonov 2016, not paginated;
STRESSOR(S)	Diminished connectivity, increased sediment and pollution loads behind dams, and raised water temperatures (3-6).	High	3. Gessner et al. 2010, not paginated; 4. He et al. 2017, pp. 7; 5. Kondrat'eva 2013 et al. pp. 133; 6. Simonov and Egidarev 2018, pp. 9–10.
- Affected Resource(s)	Dams along migration routes block sturgeon from reaching spawning grounds, and may delay spawning where water temperatures are raised (3-6).	High	3. Gessner et al. 2010, not paginated; 4. He et al. 2017, pp. 7; 5. Kondrat'eva 2013 et al. pp. 133; 6. Simonov and Egidarev 2018, pp. 9–10.
- Exposure of Stressor(s)	Tributaries of the Amur, especially the Zeya, Bureya, Songhua, and Ussuri; others with smaller dams. Not on the main stem as of 2019 (1, 7) .	Moderate	1. Simonov and Dahmer 2008, pp. 178-202; 7. Lehner et al. 2011 & GRanD 2019, not paginated
- Immediacy of Stressor(s)	Large dams built since at least 1975 (Zeya River); main stem threat continuing (7).	High	7. Lehner et al. 2011 & GRanD 2019, not paginated
Changes in Resource(s)	Inability to access spawning grounds; decreased water quality (3–5).	High	3. Gessner et al. 2010, not paginated; 4. He et al. 2017, pp. 7; 5. Kondrat'eva 2013 et al. pp. 133; Simonov and Egidarev 2018, pp. 9–10
Response to Stressors: - INDIVIDUALS	Where fish cannot reach spawning grounds, they are unlikely to breed (8); sedimentation can slow egg development (9); pollution can alter fish growth and physiology, and can cause direct mortality (e.g., 10).	Moderate	8. He et al. 2017, Table 1; 9. Li et al. 2012, pp. 557; 10. Depew et al. 2012, Table 2.

POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Reduced reproductive and recruitment success (3–5, 8).	High	3. Gessner et al. 2010, not paginated; 4. He et al. 2017, pp. 7; 5. Kondrat'eva 2013 et al. pp. 133; Simonov and Egidarev 2018, pp. 9–10; 8. He et al. 2017, Table 1.
- GEOGRAPHIC SCOPE	Tributaries of the Amur, especially the Zeya, Bureya, Songhua, and Ussuri; others with smaller dams. Not on the main stem as of 2019 (1,5).	Moderate	1. Simonov and Dahmer 2008, pp. 178-202; 5. Lehner et al. 2011 & GRanD 2019, not paginated
- MAGNITUDE	Dams have caused the extirpation of (heavily fished) populations in the Zeya, Bureya, and Songhua Rivers; could do the same in the main stem, if a dam is built there in the future and it blocks access to spawning grounds (1).	Moderate	1. Simonov and Dahmer 2008, pp. 178-202
SUMMARY	**Dams have eliminated habitat and connectivity between feeding and spawning grounds in several large Amur River tributaries; however, the main stem of the river remains free-flowing, There is not an immediate risk of dam construction there, but it is a growing possibility.**	Moderate	

Table A2.3—Causes and effects of water pollution on Amur sturgeon

Pollution			
	Analysis	Confidence	Supporting Information
SOURCE(S)	Industry, agriculture, domestic waste (1).	High	1. Simonov and Dahmer 2008, pp. 212-236
- Activity(ies)	Discharge of heavy metals, petrochemicals (e.g., benzene and PAHs), raw sewage, fertilizer, and persistent organic chemicals (e.g., PCBs) in the Amur and its tributaries (1).	High	1. Simonov and Dahmer 2008, pp. 212-236
STRESSOR(S)	Accumulation of pollutants in sturgeon tissue; development of low-oxygen dead zones due to eutrophication (2, 3).	High	2. Simonov and Dahmer 2008, pp. 220; 3. Li et al. 1989 cited in Meng et al. 2016, pp. 5
- Affected Resource(s)	Contamination of river water and sediments (4-6), and likely of sturgeon prey (7);	High	4. Li et al. 1989 cited in Meng et al. 2016, pp. 5; 5. Kondratyeva et al 2012, pp. 186; 6. Kondrat'eva et al. 2013, pp. 129; 7. Kasymov 1994 cited in He et al. 2017, pp. 10
- Exposure of Stressor(s)	In river water, sediments, and prey consumed by sturgeon (1, 8).	High	1. Simonov and Dahmer 2008, pp. 212-236; 8. Kondratyeva et al 2012, pp. 185-190
- Immediacy of Stressor(s)	Past and ongoing (2, 9).	Moderate	2. Simonov and Dahmer 2008, pp. 220; 9. Meng et al. 2016, pp. 5.
Changes in Resource(s)	Polluted water and sediments, especially in the Lower Amur and Songhua Rivers (2, 3).	High	2. Simonov and Dahmer 2008, pp. 220; 3. Li et al. 1989 cited in Meng et al. 2016, pp. 5
Response to Stressors: - INDIVIDUALS	Mortality of larva and young fish due to petrochemicals (10-11); reproductive hormone suppression (12); morphological anomalies (12); Possibly lowered immune function due to persistent organic pollutants (13);	Moderate	10. Bickham 1998, pp. 514–515; 11. Kocan et al. 1996, pp. 163; 12. Webb et al. 2006, pp. 447-450; 13. Duffy et al., 2002; pp. 560;

POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Diminished average fecundity and longevity (14);	Moderate	14. Simonov and Dahmer 2008, pp 47.
- GEOGRAPHIC SCOPE	Throughout the Amur basin, but especially in the more developed Lower Amur and Songhua River (1, 8).	High	1. Simonov and Dahmer 2008, pp. 212-236; 8. Kondratyeva et al 2012, pp. 185-190
- MAGNITUDE	Uncertain; no cohort or mark-recapture studies following the fate of Amur sturgeon experiencing different levels of pollution exposure have been completed (14).	Low	14. Simonov and Dahmer 2008, pp 47
SUMMARY	**The degree of pollution, results of limited laboratory toxicity studies, and reports of large-scale fish kills in polluted river reaches make it difficult to imagine the population has not been impacted by pollution. However, definitive evidence from field-based demographic studies linking population declines to pollution is exceedingly difficult to collect and is not available, to our knowledge. The levels of pollution and contamination at which sturgeon are affected are also somewhat uncertain.**		

Table A2.4—Causes and effects of climate change on Amur sturgeon

Climate change			
	Analysis	Confidence	Supporting Information
SOURCE(S)	Global climate change and associated temperature increases (1, 2).	High	1. Yu et al. 2013a, Table 3 & Fig. 3; 2. Karger et al. 2018, not paginated.
- Activity(ies)	Regional air temperature is increasing (2) and water temperatures will follow (1), although there is uncertainty in the exact relationship between air and water temperatures, as well as the future degree of global climate change.	High	1. Yu et al. 2013a, Table 3 & Fig. 3; 2. Karger et al. 2018, not paginated.
STRESSOR(S)	Rising water temperatures (4).	High	4. Hupfeld et al. 2015, pp. 1196–1201.
- Affected Resource(s)	Water temperature (4).	Moderate	4. Hupfeld et al. 2015, pp. 1196–1201.
- Exposure of Stressor(s)	Fish live in warming water (4, 5).	High	4. Hupfeld et al. 2015, pp. 1196–1201. 5. Chang et al. 2017, entire.
- Immediacy of Stressor(s)	Uncertain because the upper limits of Amur sturgeon thermal tolerance are unknown.	Low	
Changes in Resource(s)	Lack of cool, oxygenated water and/or access to spawning grounds.	Moderate	4. Hupfeld et al. 2015, pp. 1196–1201.
Response to Stressors: - INDIVIDUALS	Sturgeon avoid high temperature river reaches (5), partly because of dropping oxygen concentrations (4). Warm water holds less oxygen, potentially killing fish and eggs (6); however, sturgeon may grow faster in warmer water. Slightly warmer water may actually speed growth and maturation (7) and reduce exposure to extreme cold events (8, 9).	High	4. Hupfeld et al. 2015, pp. 1196–1201; 6. Lyons et al. 2015, pp. 1508; 7. Krykhtin and Svirskii 1997, pp. 234; 8. Krykhtin and Svirskii 1997, pp. 238; 9. Novomodny et al. 2004, pp. 20.

POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Reproductive success may be diminished and mortality increased if thermal tolerances are exceeded (4). However, the speed of growth and maturation may be increased in warmer water before thermal limits are reached (7, 10).	Moderate	4. Hupfeld et al. 2015, pp. 1196–1201; 7. Krykhtin and Svirskii 1997, pp. 234; 10. Krykhtin and Svirskii 1997, pp. 237.
- GEOGRAPHIC SCOPE	Entire range of the Amur sturgeon (2).	High	2. Karger et al. 2018, not paginated.
- MAGNITUDE	Uncertain, but unlikely to exceed the effects of overharvesting, pollution, or dams in the next 30 years (11).	Low	11. Osipov 2020, pers. comm..
SUMMARY	**Although it may eventually impact the availability of suitable habitat, climate change it is uncertain whether climate change will rise to become a major risk factor for Amur sturgeon in the next 30 years.**	Somewhat	

Table A2.5—Causes and effects of hybridization on Amur sturgeon

Hybridization			
	Analysis	Confidence	Supporting Information
SOURCE(S)	Genes from hybrid sturgeon escaped from aquaculture may enter wild populations (1).	High	1. Zhang et al. 2013, pp. 8.
- Activity(ies)	Large fish farms are breeding Amur sturgeon hybridized with Siberian and kaluga sturgeon hybrids, especially in Chinese portions of the Amur basin (2). The potential exists for these fish to escape and breed with wild Amur sturgeon.	High	2. Bronzi et al. 2019, pp. 260 & Fig. 11.
STRESSOR(S)	Potential presence of escaped, farmed hybrid sturgeon; especially risky in proximity to spawning Amur sturgeon (1).	Moderate	1. Zhang et al. 2013, pp. 8.
- Affected Resource(s)	Ability to mate with conspecifics (1).	High	1. Zhang et al. 2013, pp. 8.
- Exposure of Stressor(s)	Where escaped hybrids encounter spawning wild Amur sturgeon.	High	1. Zhang et al. 2013, pp. 8.
- Immediacy of Stressor(s)	Chinese sturgeon aquaculture grew by ~400% between 2010 and 2017 and careless farm management (3) may be allowing fish escapes now, although no cases of wild Amur sturgeon hybridization with escaped fish are confirmed.	Somewhat	1. Zhang et al. 2013, pp. 8 3. Li et al. 2009, pp. 636;
Changes in Resource(s)	Lower proportion of spawning fish that are wild Amur sturgeon.	High	1. Zhang et al. 2013, pp. 8.
Response to Stressors: - INDIVIDUALS	Mating of wild Amur sturgeon with escaped hybrid fish. Although no such cases are documented yet, Amur sturgeon do naturally hybridize with wild kaluga sturgeon on their shared spawning grounds (4).	Moderate	4. Azuma et al. 2016, pp. 143

POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Natural hybrids of Amur and kaluga sturgeon may be sterile (5) and are 80% male (6). If hybrid offspring of wild and farmed fish have similar traits, sex ratios and reproductive success of wild populations may suffer.	Somewhat	5. Billard and Lecointre 2001, pp. 369; 6. Krykhtin and Svirskii 1997, pp. 237
- GEOGRAPHIC SCOPE	Throughout the species' range, but especially the Lower Amur, where most farms are located (2).	Moderate	2. Bronzi et al. 2019, pp. 260 & Fig. 11.
- MAGNITUDE	Uncertain. It is very difficult to know the frequency of farmed fish escapes and whether they are breeding. Thus, the degree to which their genetic dilution of wild populations is occurring is unclear.	Low	
SUMMARY	**The escape of sturgeon from aquaculture facilities risks their breeding with wild Amur sturgeon, co-opting viable eggs and sperm but producing sterile, sex-ratio-biased or maladapted offspring. However, the details and frequency of this interaction are poorly known.**	Somewhat	

Table A2.6—Causes and effects of disease and predation on Amur sturgeon

Disease and predation			
	Analysis	Confidence	Supporting Information
SOURCE(S)	*Polypodium hydriforme* appears to be the most important parasite or pathogen for wild Amur sturgeon conservation (1, 2). Others (e.g., nematodes; 3) are not known to cause significant morbidity in sturgeon hosts. There is no evidence of changing predation rates.	High	1. Raikova 2002, pp. 405-415; 2. Koshelev 2104b, pp. 1127; 3. Finogenova 1967, pp. 93 - 98;
- Activity(ies)	*P. hydriforme* is a cnidarian parasite that infects and kills sturgeon oocytes; it consumes the yolk and prevents sturgeon embryo development (4).	High	4. Raikova 2002, pp. 412-413;
STRESSOR(S)	Direct effect on individual reproductive output (1).	High	1. Raikova 2002, pp. 405-415
- Affected Resource(s)	Direct effect on individual reproductive output (1).	High	1. Raikova 2002, pp. 405-415
- Exposure of Stressor(s)	*P. hydriforme* infection occurs when its free-living stage infects sturgeon, possibly as early as their larva stage (4).	High	4. Raikova 2002, pp. 412-413;
- Immediacy of Stressor(s)	Known in Amur sturgeon since at least 1984 (5).	High	5. Svirskii 1984, entire.
Changes in Resource(s)	Direct effect on individual reproductive output (1).	High	1. Raikova 2002, pp. 405-415
Response to Stressors: - INDIVIDUALS	Infected eggs die.	High	1. Raikova 2002, pp. 405-415

POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Reduction in rate of reproductive success proportional to the number of infected eggs (4). In the most recently reported sampling, less than 1% of eggs were infected (2).	High	4. Raikova 2002, pp. 412-413; 2. Koshelev 2104b, pp. 1127
- GEOGRAPHIC SCOPE	*P. hydriforme* infects sturgeon species worldwide (7) and is likely widespread in the Amur sturgeon range, although there has not be an explicitly spatial analysis of its range.	Moderate	7. Raikova 2002, Table 1;
- MAGNITUDE	Among ~550 female Amur sturgeon captured between 2005 and 2009, 57.1% had eggs infected with *P. hydriforme* (2). Only 1% of eggs in infected Amur sturgeon contained the parasite, though (2). The recorded prevalence and intensity of infection in Amur sturgeon is moderate among sturgeon species (7), and given the heavily R-selected nature of Amur sturgeon (many eggs, few individuals survive to maturity), it is unlikely that 1% mortality of eggs yields a significant impact on reproductive output.	Moderate	2. Koshelev 2104b, pp. 1127; 7. Raikova 2002, Table 1
SUMMARY	**Disease and predation do not represent important threats to the survival of Amur sturgeon at present and there is no indication their impacts will change in the future.**	High	

APPENDIX III—CONSERVATIVE POPULATION SIZE THRESHOLDS FOR RESILIENCE SCORING

We are not aware of historic population size estimates for Amur sturgeon dating to the period before intense human harvest of the species. However, their population size—and specifically the number of reproductive females—is a critical determinant of the species' resiliency. Therefore, to determine abundance thresholds for use in scoring analysis units' resiliencies (Table 2.2), we made the calculations and assumptions below to bound the number of reproductive females in populations of very low, low, moderate, and high resiliency. We based these estimates on the best available data regarding the species' abundance, from as long ago as possible, to best represent a condition less affected by modern commercial exploitation.

Throughout, where there was uncertainty, we deliberately used (often highly) conservative choices. This decision, if anything, biases our estimates of historical population sizes downwards and encourages scoring of depleted current and future populations as relatively abundant (healthy) compared to the historical condition.

Estimating mature female abundance in populations of high, moderate, low, and very low resilience

1. 607 metric tons Amur sturgeon were captured in 1891, with 89% (546,300 kg) of this from the Middle Amur analysis unit (Krykhtin and Svirskii 1997, pp. 237).

2. The average length of Amur sturgeon caught in the Lower Amur in 1929 and 1930 was 90.1 cm and that of fish caught in the Amur Estuary was 173.0 cm (Koshelev et al. 2014a, Table 5). We are not aware of such old estimates for the Middle Amur. If we assume that the size of captured Amur sturgeon had not begun to drop due to overfishing in 1929 (Koshelev et al 2014b, pp. 1129–1130), we can estimate the average weight of a fish caught in 1891 using the equation $y = ax^b$, where y is a fish's weight in kg, x its length in cm, and a and b are scaling coefficients that describe the length-to-weight relationship (Gayon 2000, entire; Schmidt-Nielson 1984, pp. 121–132). For Amur sturgeon, a is estimated to be 1.0×10^{-6} and b 3.3169 (Ji et al. 2012, Fig. 1). We use these values to compute lower and upper estimates for the average weight of fish captured in 1891.

   $y = 10^{-6} * 90.1^{3.3169} = 3.05$ kg; *low-end estimate of mean historical Amur sturgeon weight*
   $y = 10^{-6} * 173.0^{3.3169} = 26.51$ kg; *high-end estimate of mean historical Amur sturgeon weight*

3. By pairing our estimate of the biomass of Amur sturgeon caught in 1891 in the Middle Amur with the high-end estimate of historical fish size, we obtain a low-end estimate the number of fish caught in 1891 in the Middle Amur:

   546,300 kg / 26.51 kg per fish = 20,607 fish

4. To estimate the total number of fish in the Middle Amur in 1891, we then used 0.01 and 0.1 as lower and upper bounds on the proportion of the total fish population captured in that year.

   Low estimate: 20,607 fish captured / 0.1 = 206,070 fish
   High estimate: 20,607 fish captured / 0.01 = 2,060,700 fish.

5. Finally, we assumed a 50-50 sex ratio and that 32.8% of the population was reproductively mature, the same proportion found recently in the Amur estuary, the analysis unit in the best condition today (Koshelev et al. 2014a, pp. 1310). This gave us low- and high-end estimates of the number of mature reproductive females in a highly resilient population.

   206,070 * 0.5 * 0.328 ≈ 34,000 reproductively mature females.
   2,060,700 * 0.5 * 0.328 ≈ 340,000 reproductively mature females.

6. Conservatively using the low value as a minimum number of reproductive females in a healthy population, we then made the following cutoffs:
   High: 34,000+ reproductively mature females
   Moderate: 10,000–33,999 reproductively mature females
   Low: 1000–9999 reproductively mature females
   Very low: < 1000 reproductively mature females

APPENDIX IV—CLIMATE CHANGE ANALYSIS

We calculated the projected future change in mean annual air temperature for the Amur River region (see *Climate change* in Chapter 4) from a set of climate models for the period 2041–2060. We downloaded high spatial resolution (~560m) model outputs 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 (Karger et al. 2018, not paginated; Karger et al. 2017, entire). We downloaded model outputs and the CHELSA representation of recent historical annual mean temperature (1979–2013) in geoTiff format.

For future projections, we used CHELSA data from climate models (Table A3.1) 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, Fig. 4; www.chelsa-climate.org/future). This helps maximize the benefits of including multiple models, which is 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 A3.1—The seven global climate models used for computing future projections of Amur River region mean annual temperatures

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 all 2nd-level Russian (districts) and Chinese (prefectures) administrative boundaries bordering the Amur River's main stem and estuary (Fig. A3.1). Within this area of interest, we then averaged the future temperature projections across all seven models and subtracted the corresponding mean annual temperatures for 1979–2013. Subtracting the historical mean temperature from projected temperatures gives the projected change in temperature.

We repeated the analysis for each of two Representative Concentration Pathways (RCPs), RCP4.5 and RCP8.5. These are 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, pp. 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, pp. 54). RCP4.5 is based on a lower-emissions future in which renewable energy, greater energy efficiency, and carbon capture and storage as more widely implemented (Thomson et al. 2011, pp. 77).

Under RCP4.5, mean annual air temperature for the region is projected to increase by 2.1 ± 0.8 SD °C; under RCP8.5, this value is 2.8 ± 1.4 SD °C. In both cases, warming is projected to be greater closer to the Pacific coast (downstream).

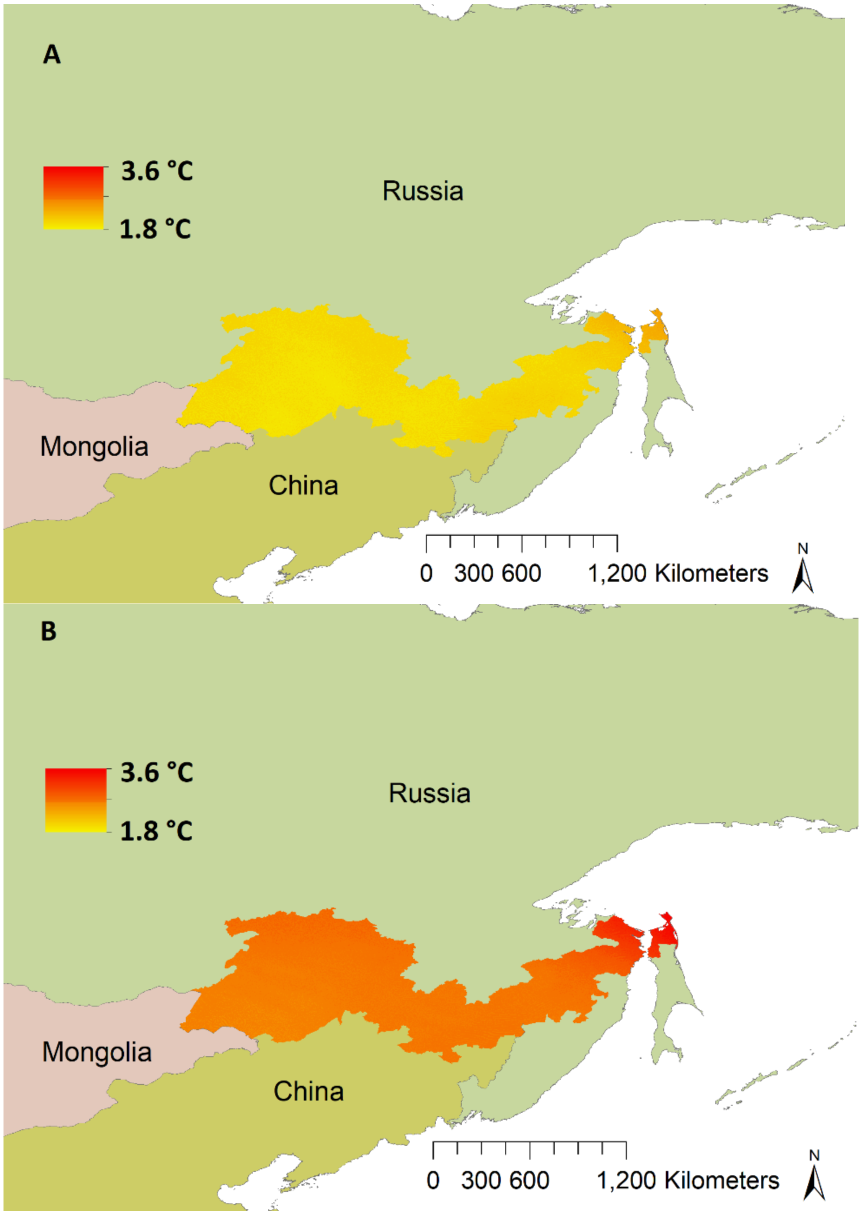

Fig. A3.1—Projected change in mean annual air temperature for 2041–2060 in the 2nd-level administrative divisions of China and Russia that border on the Amur River's main stem and estuary. Top panel (A) shows the IPCC's RCP4.5 scenario; bottom panel (B) shows the RCP8.5 scenario. Data from Karger et al. (2017 & 2018).

APPENDIX V—LESLIE MATRIX MODEL DETAILS

We used modified Leslie matrix models (Heppell et al. 2000, pp. 152) to simulate the future trajectory of Amur sturgeon populations in each analysis unit. The models proceed from an initial condition representing the year 2020 for which we specify a starting population size and age-class distribution. Then, future population sizes and age distributions are projected at successive annual time steps for 30 years. Future population sizes are computed by multiplying the population size for each age class by the probability that its individuals survive to the following age class; mature individuals add new fish to the population at each time step and die at a prescribed rate. By convention, only females are modeled; male abundance is assumed to be sufficient for fertilization of all eggs (Heppell et al. 2000, pp. 152; Jaric and Gessner 2013, pp. 484).

We included 10 age classes (Tables A4.1):

- Individuals less than 1 year old;
- Juveniles comprising each of eight age classes from age 1 through age 8;
- Mature, reproductive individuals; i.e., those at least 9 years age.

We used consistent age-specific survival, maturation, fecundity, and frequency of reproduction across all modeled future scenarios (Table A4.1), with population sizes differing by analysis unit. These are given in Tables A4.2–A4.4 for the Estuary, Lower Amur, and Middle Amur units; the Upper Amur unit is extirpated as of 2020, so models of this unit (restocking in Scenarios 2 & 3) used initial population sizes of 0 for all age classes. To select a juvenile (year 1–year 8) survival rate from the range of values in the literature, we ran all scenario 1 models using juvenile survival rates of 0.20, 0.55, 0.64, 0.68, 0.72, and 0.89. We selected the largest (most conservative or optimistic) survival rate which produced declining populations in this scenario. This matches our best understanding of the present condition of the species and its extant analysis units (Ruban and Qiwei 2010, not paginated).

Table A4.1—Demographic parameters for all models

Parameter	Values	Justification/citation
Average fecundity (production of females) per female, in years reproducing	143,890	Empirically determined from 317 captured females, then halved to represent only female offspring (Krykhtin and Svirskii 1997, pp. 237).
Frequency of reproduction	Every 4 years	(Novomodny et al. 2004, pp. 19; Zhuang et al. 2002, pp. 659; Wei et al. 1997, pp. 244)
Annual survival of fish < 1 year old	0.00053	High-end estimate from range of 0–0.00053 for several *Acipenser* spp.; very low because these are highly r-selected species (Jaric and Gessner 2013, Table 1; Jager et al. 2001, Table 1).
Annual survival of fish aged 1–7 years	0.68	Literature-indicated a range of 0.2–0.89 for annual survival of juveniles of several *Acipenser* spp. (Jaric and Gessner 2013, Table 1; Jager et al. 2001, Table 1). This is the highest value that produced declining population trajectories for the Scenario 1 *status quo* models, in line with our knowledge of the current status of the species.
Annual survival of fish aged 8 years to reproduce in year 9; assumes fish are subject to harvest as soon as they mature, potentially before spawning.	0.37	Compound probability of 0.68 [the high-end probability of surviving from year 8 to maturity (year 9)] *x* 0.54 [the proportion of adult females that survive annually] (Jaric and

		Gessner 2013, Table 1; Simonov and Dahmer 2008, pp. 47; Jager et al. 2001, Table 1).
Age at first reproduction	9 years	Low-end estimate from range of 9–14 years in literature (Wei et al. 1997, pp. 244; Krykhtin and Svirskii 1997, pp. 234).
Annual survival of mature fish	0.54	0.74 baseline adult survival * 0.71 prop not breeding + 0.05 survival of spawning fish * 0.29 proportion spawning (Ruban and Qiwei 2010, not paginated; Simonov and Dahmer 2008, pp. 47; Krykhtin and Svirskii 1997 pp. 236; Jager et al. 2001, Table 1).

Table A4.2—Initial population for the Amur estuary models

Parameter	Value(s)	Justification/citation
Initial mature (9+ years old) population, females	28,860	Estimated 264,000 fish >1 year old * 32.8% mature * 33.33% mature fish female (Koshelev et al. 2014a pp. 1310; Koshelev et al. 2014b, pp. 1127)
Initial population per juvenile age class (1–8 years old), females	11,088	Estimated 264,000 fish >1 year old * 67.2% immature * 50% female, evenly distributed across 8 immature age classes (Koshelev et al. 2014a pp. 1310, 1312–1316; Wei et al. 1997, pp. 244)
Fish < 1 year old	1.04 billion	143,890 (Average fecundity, females) * ¼ (fraction of females reproductive annually) * 28,860 (initial number of females) (Krykhtin and Svirskii 1997, pp. 236–237)

Table A4.3—Initial population for the Lower Amur models

Parameter	Value(s)	Justification/citation
Initial mature (9+ years old) population, females	425	Estimated 25,000 fish >1 year old * 5.1% mature * 33.33% mature fish female (Koshelev et al. 2014a, pp. 1310, 1312–1316; Koshelev et al. 2014b, pp. 1127)
Initial population per juvenile age class (1–8 years old), females	1483	Estimated 25,000 fish >1 year old * 94.9% mature * 50% female, evenly distributed across 8 immature age classes (Koshelev et al. 2014a pp. 1310, 1312–1316; Koshelev et al. 2014b, pp. 1127)
Fish < 1 year old	15.3 million	143,890 (Average fecundity, females) * ¼ (fraction of females reproductive annually) * 425 (initial number of females) (Krykhtin and Svirskii 1997, pp. 236–237)

Table A4.4—Initial population for the Middle Amur models

Parameter	Value(s)	Justification/citation
Initial mature (9+ years old) population, females	85	Optimistic estimate of 5,000 fish >1 year old * 5.1% mature * 33.33% mature fish female (Koshelev et al. 2014a pp. 1310, 1312–1316 calls unit nearly extirpated; Koshelev et al. 2014b, pp. 1127)
Initial population per juvenile age class (1–8 years old), females	297	Optimistic estimate of 5,000 fish >1 year old * 94.9% mature * 50% female, evenly distributed across 8 immature age classes (Koshelev et al. 2014a pp. 1310, 1312–1316; Koshelev et al. 2014b, pp. 1127)

Fish < 1 year old	3.05 million	143,890 (Average fecundity, females) * ¼ (fraction of females reproductive annually) * 85 (initial number of females) (Krykhtin and Svirskii 1997, pp. 236–237)

Models for Scenario 1, the *status quo* future, were run using only the parameters prescribed above. This represents a future with a continued high rate of harvest of adult females for the caviar and meat trade.

Scenario 2 represents a future where aquaculture efforts are partially redirected towards the restocking of Amur sturgeon populations using very young fish—fry around 30 days of age. To model this restocking effort, we used the same parameters as in Scenario 1, but also added 1.25 million fish to the less-than-1 year old age class at the start of each time step. These fish then progressed through successive years of the model. The choice of 1.25 million fish was to represent the 50% of 2.5 million fish released in each analysis unit (1/4 of the 10 million total fish recommended for annual restocking efforts; Krykhtin and Gorbach 1994 cited in Koshelev et al. 2014a, pp. 1316) that would be female.

Scenario 3 was identical to Scenario 2 except that we modeled the addition of fewer, older fish. Instead of fry, we considered the effects of restocking each year with 62,500 year-old females per analysis unit.

Sensitivity test

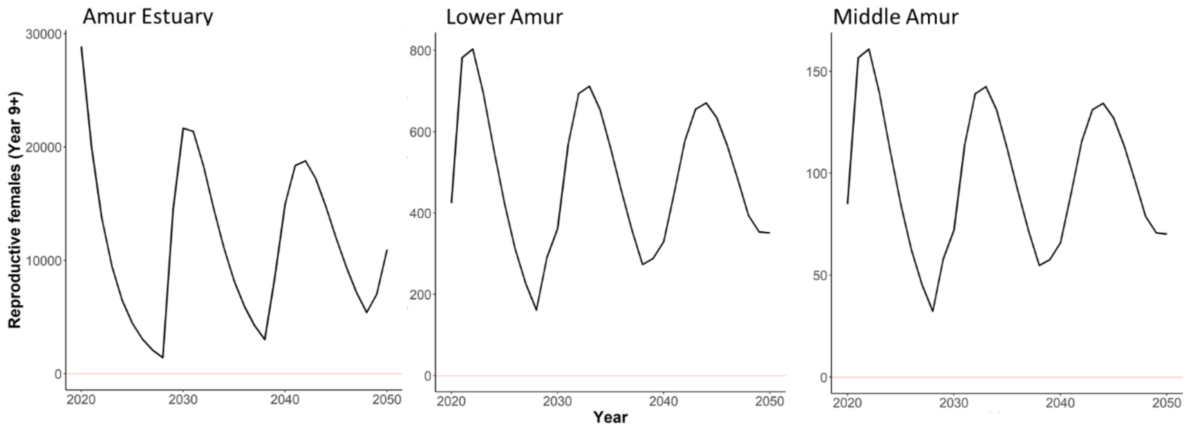

Figure A4.1—Population projections for mature females (age 9 and up) in each of the three extant analysis units between 2020 and 2050 under the *status quo* future (Scenario 1), but with the survival of mature females twice the best available estimate. Note the different y-axis scales. Red lines at 0.

Table A4.5—Resilience in 2050 of extant analysis units under a *status quo* future scenario, but with the survival of mature females twice the best available estimate

Resilience criteria	Amur Estuary	Lower Amur	Middle Amur
Number of reproductive females (2040–2050 range given to capture cycling population)	5396–18,782 *2–4 points*	330–671 *0 points*	66–134 *0 points*
Water quality to support prey availability and sturgeon health	Receives water pollution from all upstream reaches, including. the heavily polluted Songhua and Lower Amur. May impact sturgeon health and prey abundance. *2 points*	Heavy industrial presence and human population density; likely impacts sturgeon health and prey abundance. *1 point*	Songhua River includes the most polluted sections of the Amur Basin; Medium-sized cities Heihe and Blagoveschensk deposit sewage, industrial waste into the reach of the Amur; likely impact sturgeon health and prey abundance. *1 points*
Survival and growth of females to reproduce with high fecundity	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	High fishing pressure. Estimated 95% of spawning fish captured annually. Also, size of captured fish and proportion of fish that are large females are declining; limits average fecundity. *1 point*	Few reproductive fish are found. *1 point*
Connectivity between spawning and feeding grounds	No dams. Fish can move into the main stem of the river to reach spawning grounds. *3 points*	No known barriers to connectivity. *3 points*	Songhua, Nen, Zeya, and Bureya River dams prevent fish from reaching spawning sites. Main stem remains without obstructions. *2 points*
Total score	**8–10 points; moderate resiliency**	**5 points; low resiliency**	**4 points; very low resiliency**
Orange text indicates a decrease in the metric from the present; Blue text indicates an improvement; Black text indicates no change.			

Modeling software

All models were run in the software R *v*3.6.1(R Core Team 2019, not paginated) and using the packages *MASS* (Venables and Ripley 2016, entire), *scales* (Auguie 2017, not paginated), *ggplot2* (Wickham 2016, not paginated), and *gridExtra* (Wickham 2018, not paginated) for modeling and presentation of results. An example code for Scenario 1's Amur estuary model follows.

```
library(MASS)
library(scales)
library(ggplot2)
```

```
library(gridExtra)

##Amur Estuary
A <- matrix(c(0, 0, 0, 0, 0, 0, 0, 0, 0, 35973,
            0.00053, 0, 0, 0, 0, 0, 0, 0, 0, 0,
            0, 0.68, 0, 0, 0, 0, 0, 0, 0, 0,
            0, 0, 0.68, 0, 0, 0, 0, 0, 0, 0,
            0, 0, 0, 0.68, 0, 0, 0, 0, 0, 0,
            0, 0, 0, 0, 0.68, 0, 0, 0, 0, 0,
            0, 0, 0, 0, 0, 0.68, 0, 0, 0, 0,
            0, 0, 0, 0, 0, 0, 0.68, 0, 0, 0,
            0, 0, 0, 0, 0, 0, 0, 0.68, 0, 0,
            0, 0, 0, 0, 0, 0, 0, 0, 0.37, 0. 54), nr = 10, byrow = TRUE)
##The modified Leslie matrix.
#The first row gives age-class specific fecundities. Only the last (mature) age class reproduces. 35973 is the average fecundity
divided by 4 because females reproduce quadrennially in the model.
#Following rows represent each of the ten age classes. Values on the diagonal give the probability that fish survive and advance
to the next age class. The final value (0.05) is the probability that a mature fish remains in this final age class the following year,
i.e., that it survives.

# initial population vector N0 gives starting population size by age class
N0 <- matrix(c(1040000000, 11088, 11088, 11088, 11088, 11088, 11088, 11088, 11088, 28860), ncol = 1)

years <- 30 #Model timeframe in years
N.projected <- matrix(0, nrow = nrow(A), ncol = years+1) #creates an empty matrix
N.projected[, 1] <- N0 #fills column 1 with initial population

#matrix multiplication looping through the years and propagating the population according to demographic rates in the matrix A.
for (i in 1:years)
{
  N.projected[, i + 1] <- A %*% N.projected[,i]
#%*% is a matrix multiplier command and carries out the successive annual propagation of the population according to
demographic rates in the matrix A.
} #Each column in N.projected is a year’s age-structured population, equal to the previous year’s population x stage-specific
survival rates, with new offspring added to the first age class and mature individuals removed on death.

#formatting as a dataframe for plots
test = as.data.frame(t(N.projected))
test[,11] = c(2020:2050) #creating a year column
colnames(test) = c("Y0", "Y1", "Y2", "Y3", "Y4", "Y5", "Y6", "Y7", "Y8", "Mature", "Year")
test$not.mature = rowSums(test[,1:9]) #total N < 9 years old.
test$total = rowSums(test[,1:10]) #total N
test$one.up = rowSums(test[,2:10]) #total N >1 year old.

#mature fish plot
E1 = ggplot(test, aes(Year, (Mature))) + geom_line(size=1) + theme_classic() + geom_hline(yintercept = 0, color="red", lwd=.1) +
ylab("Reproductive females (Year 9+)") + theme(axis.text=element_text(size=15.5),
axis.title=element_text(size=19,face="bold"))+ ggtitle("Amur estuary")
```