Atlantic sturgeon (*Acipenser oxyrinchus*) and European sturgeon (*A. sturio*) in the Nordic Region: A review of the species' biology, immigration history, threats, and restoration measures

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Sammendrag

Atlantisk stør (Acipenser oxyrynchus) og Europeisk stør (A. sturio) i Norden; en gjennomgang av artenes biologi, innvandringshistorie, trusler og restaureringstiltak. I nordiske elver og marine områder er Atlanterhavsstør (*Acipenser oxyrinchus*) den dominerende størarten. Denne arten, som opprinnelig stammer fra Nord-Amerika, koloniserte Østersjøen for om lag 4 000–5 000 år siden, og har fortrengt den europeiske støren (*A. sturio*) de siste 2 000 årene. Størens gytevandring preges av sterk *homing* og kan strekke seg over flere hundre kilometer og omfatter flere distinkte faser i havet, estuariene og ferskvannssystemene. Den benytter seg av ulike navigasjonsmekanismer for å finne tilbake til sin opprinnelige elv og gyteplass. Gytingen foregår på grus- eller steinbunn i strømrike partier av elver. De klebrige eggene fester seg til substratet og klekkes innen 4–7 dager, avhengig av vanntemperaturen. Hunnene gyter hvert tredje til femte år, mens hannene vanligvis gyter annethvert år. Ungene starter med å beite på små planktonorganismer før de går over til større bunndyr. Voksne individer livnærer seg derimot på småfisk, bløtdyr, krepsdyr og insektlarver. Ungene lever 1-6 år i ferskvann før utvandring til marint miljø. Atlanterhavsstør kan bli over 60 år gamle, vokse til 4,3 meter og nå en vekt på opptil 368 kg. De største truslene mot størbestandene i Norden har vært overfiske, habitatforringelse og brudd i vandringskorridorer som følge av vannkraftutbygging. Viktige tiltak for bevaring og gjenoppbygging av gjenværende bestander inkluderer fiskeriregulering, restaurering av gytehabitater, avlsprogrammer i fangenskap, informasjonsarbeid og internasjonalt samarbeid. Studien omtaler også forekomsten av stør i elvesystemer i Sverige, Finland og Norge.

Summary

In Nordic rivers and marine areas, the predominant sturgeon species has been the Atlantic sturgeon (*Acipenser oxyrinchus*). This sturgeon species, originally from North America, colonized the Baltic Sea as early as 4,000–5,000 years ago and has outcompeted the European sturgeon (*A. sturio*) for at least the past 2,000 years. The spawning migration of sturgeon is charac-

terised by strong homing and may cover hundreds of kilometres and consists of several distinct oceanic, estuarine and freshwater phases. Multiple navigation mechanisms are employed to locate their natal river and spawning sites. Spawning occurs on gravel or rocky substrates in fast flowing water. The adhesive eggs attach to the substrate and hatch within 4–7 days, depending on water temperature. Females spawn every 3 to 5 years, while males typically spawn every other year. Juveniles initially feed on small planktonic organisms before transitioning to larger benthic invertebrates, while adults consume small fish, molluscs, crustaceans, and insect larvae. Juveniles stay 1-6 years in freshwater before seaward migration. Atlantic sturgeon can live over 60 years, grow up to 4.3 meters in length, and reach a weight of 368 kg. The main threats to sturgeon populations in the Nordic region have been overfishing, habitat degradation, and disruptions to connectivity caused by hydropower development. Key conservation and restoration measures for remnant populations and stock recovery include fishery regulations, restoration of spawning habitats, captive breeding programs, public awareness initiatives, and international collaboration. This study also discusses the presence of sturgeon in Swedish, Finnish and Norwegian river systems.

Introduction

Sturgeons (*Order: Acipenseriformes; Family: Acipenseridae*) represent one of the oldest groups of bony fishes, with an evolutionary history spanning over 200 million years. Most sturgeon species are long-lived, grew to large sizes, and exhibit late sexual maturation. With few exceptions, sturgeons are anadromous and spawn in freshwater and migrate to brackish og salt water to feed and grow. Thus, they undertake extensive migrations between marine environments, brackish estuaries, and freshwater rivers (Bemis & Kynard 1997). These life history traits render sturgeon populations highly vulnerable to overexploitation and habitat modifications that disrupt spawning and juvenile development in riverine and estuarine systems.

Habitat alterations affecting sturgeon populations include dredging of riverbeds and deltas, flood control measures, river channelization, and the construction of hydroelectric dams and associated reservoirs. The cumulative impacts of these environmental changes, particularly the degradation of habitat quality, reduction in carrying capacity, and loss of longitudinal connectivity, have led to severe population declines and local extinctions (Rochard et al. 1990; Birstein et al. 1997; Puijenbroek et al. 2019). Sturgeons are now considered the most endangered order of vertebrates globally, with the IUCN Red List estimating that 85% of all sturgeon species face some level of threat. Large-scale restoration efforts aimed at improving habitat conditions and re-establishing connectivity are essential for population recovery. However, given the extent of different threats, it is unlikely that most sturgeon populations will recover beyond minimally viable levels. As a result, harvestable populations remain out of reach.

In Nordic waters, two sturgeon species have been recorded; the Atlantic sturgeon (*Acipenser oxyrinchus,* Mitchill 1815) and the European sturgeon (*Acipenser sturio,* Linnaeus, 1758). Both species are anadromous, spending most of their lives in marine environments and migrate into freshwater rivers to spawn. Juveniles of Atlantic sturgeon inhabit riverine habitats for 1-6 years before they out-migrate to estuarine habitats before migrating further to marine environments. Duration of the freshwater stage is influenced by water temperature, growth and nutritional conditions (Kynard et al 2000; Dadswell et al 2017). Juvenile European sturgeon remains in freshwater for up to 2–3 years before migrating to the sea. Seaward migration is initiated by mainly the same environmental cues as for Atlantic sturgeon, were achieved body size, physiologic development stage and osmoregulatory capability are important criteria to leave freshwater systems (Rochard et al 1990; Gessner & Tesch 1996).

Historically, the Atlantic sturgeon (Figure 1) was widespread in several major rivers draining into the Baltic Sea, while the European sturgeon had a broader distribution along the coasts of the North Atlantic, the Mediterranean, and the Black Sea. However, throughout the 20th century, both species suffered drastic population declines and local extinctions. As in other European river systems, overfishing and habitat destruction, primarily caused by hydropower development, flood control measures, and pollution, were the main drivers of these declines. In response, multiple conservation and reintroduction programs have been initiated across various countries. Notably, in June 2024, Atlantic sturgeon was reintroduced into the Göta älv in Sweden as part of a broader European initiative to restore viable populations (https://www.sverigesnatur.org/aktuellt/atlantstoren-atervander-slapps-ut-i-gota-alv/?utm_source=chatgpt.com).

The objective of this article is 1) to provide a biological and historical overview of the two sturgeon species occurring in the Nordic region: the Atlantic and European sturgeon. 2) to clarify their historical origins and current distributions. The biological section of this article covers aspects of migration and spawning biology, feeding ecology, growth, age, and the factors contributing to their extensive population declines. Furthermore, an overview of historical sturgeon occurrences in different Nordic countries is provided. A brief mention of the Great Beluga Sturgeon (Huso huso) is also included. Finally, it is given some speculations on which of the Norwegian river systems that may have functioned as sturgeon spawning habitats until the Middle Ages.

Sturgeon species in the Nordic region

Of the 27 extant species within the sturgeon family (*Acipenseridae*), nine are found in Europe: *Huso huso, Acipenser sturio, A. nudiventris, A. naccarii, A. persicus, A. gueldenstaedti, A. stellatus, A. ruthenus*, and *A. oxyrinchus* (Holčík, 1989; Popović et al., 2014). Until the mid-19th century, these species were widely distributed across European waters.

Early genetic studies suggested that the Atlantic sturgeon colonized the Baltic Sea during the Middle Ages, outcompeting the European sturgeon in Nordic River systems (Ludwig et al., 2002). This remarkable transatlantic migration may have been driven by significant climatic shifts that altered oceanic currents and temperature regimes over several centuries, creating favourable conditions for species dispersal.

More recent genetic analyses have corroborated this hypothesis. Popović et al. (2014) investigated the historical distribution of sturgeon in the Baltic Sea to clarify the relationship between the Atlantic and European sturgeon. Earlier assumptions suggested that Atlantic sturgeon migrated from North America to the Baltic Sea approximately 1200 years ago, coinciding with the onset of the Little Ice Age. To test this hypothesis, the researchers analysed DNA from 188 ancient sturgeon specimens retrieved from archaeological sites and museum collections in Poland, comparing them to 225

Figure 1. Atlantic sturgeon drawing (source: U.S Fish and Wildlife Service).

contemporary samples from North American and European populations.

The results revealed that out of 125 ancient sturgeon samples from the Baltic Sea, only four (3.2%) were identified as European sturgeon, while the remainder belonged to the Atlantic sturgeon. Furthermore, the historical Baltic population exhibited considerable genetic polymorphism and was distinct from modern populations. The study also provided evidence that Atlantic sturgeon colonized the Baltic Sea as early as 4,000–5,000 years ago, significantly earlier than previously assumed. Additionally, genetic analyses detected introgression from European sturgeon into the genome of Atlantic sturgeon, indicating past hybridization between the two species.

The study also concluded that Atlantic sturgeon has dominated the Baltic Sea and its associated river systems for the past 2,000 years, with the most genetically similar extant populations found in Canada's St. John and St. Lawrence rivers (Popović et al. 2014). These Canadian populations are now considered the most suitable broodstock for ongoing sturgeon restoration programs in Poland and Germany.

Throughout history, only two sturgeon species were harvested in Nordic waters and river systems before their populations collapsed. Archaeological records suggest that their distribution remained largely unchanged until the 17th or 18th century (Tsepkin & Sokolov, 1979). At that time, large river systems such as the Dnieper, Don, Volga, and Ural served as critical spawning and nursery habitats, with individuals frequently reaching body weights of several hundred kilograms. However, intensive exploitation and habitat modifications led to dramatic population declines and, ultimately, local extinctions

The European sturgeon

The European sturgeon was once widespread across southern Europe but is now considered functionally extinct and critically endangered (CR) by International Union for Conservation of Nature (IUCN) red list in most of its historical range. It now survives only as a remnant population in the Gironde–Garonne–Dordogne River system in France, with intensive conservation and restocking efforts underway. Historically, it had the broadest distribution of all European sturgeon species. Today, however, natural spawning occurs in only two river systems: the Gironde (France) and the Rioni (Georgia). The Gironde population consists of a few thousand individuals, with ongoing natural reproduction. In Sweden, only a few confirmed historical catches of this species have been documented. The species is classified as endangered or extinct in several European countries and is strictly protected under the CITES convention.

Historically, Atlantic and European sturgeon were considered a single species. However, subsequent genetic and morphological studies have demonstrated that the Atlantic sturgeon is a distinct species with a separate evolutionary lineage. The European sturgeon is native to Europe, whereas the Atlantic sturgeon originates from North American populations that migrated across the Atlantic and established populations in the Baltic Sea (see Popović et al., 2014). Thus, the Norwegian catch records of sturgeons are probably both Atlantic and European sturgeon. In some contexts, the Atlantic sturgeon in the Baltic is referred to as the Baltic sturgeon.

The Atlantic sturgeon

Historically, the Atlantic sturgeon was widely distributed along the coasts of both North America and Europe. Though once severely depleted by overfishing and habitat degradation along the Atlantic coast of North America, several distinct population segments are now stable or recovering due to conservation measures. However, threats from bycatch, dam obstruction, and habitat loss remain. The IUCN red list status is near threatened (NT). On the European side of the Atlantic, its range extended across marine, fjord, and riverine ecosystems from the Bay of Biscay to the Baltic Sea. Large historical populations have been documented in major river systems such as the Rhine, Elbe, and Oder

(Rochard et al., 1990). In North America, the species was once abundant in the Hudson River, the St. Lawrence River, and multiple other rivers along the East Coast (Scott & Crossman, 1973). While some populations persist, they are under increasing pressure from hydropower development, overfishing, and habitat degradation (Smith, 1985).

Like many of its relatives, the Atlantic sturgeon is known for its economic value as a source of high-quality caviar, its considerable size, and its complex life history. The species historically played a vital ecological and economic role in the major Nordic and Baltic River systems surrounding the Baltic Sea. However, due to habitat destruction, overexploitation, and disruptions to riverine hydrological cycles, many populations are now extinct or critically endangered.

Morphological differences between Atlantic and European sturgeon

Although the Atlantic and European sturgeon are morphologically similar, they can be distinguished based on key physical characteristics. The Atlantic sturgeon is characterized by a long, pointed snout and possesses 11–14 dorsal scutes. In contrast, the European sturgeon has a shorter, blunter snout and 9–13 dorsal scutes (Ludwig et al., 2002; Magnin, 1964).

The following sections will discuss research on both sturgeon species, as they share significant biological traits and conservation challenges. However, before delving into these aspects, a brief overview of the world's largest sturgeon species is provided:

The Great Beluga sturgeon

The Beluga sturgeon, also known as "The Great Beluga Sturgeon," is the largest sturgeon species in the world and warrants mention in this context (Figure 2). It inhabits the Caspian Sea (bordering Russia, Kazakhstan, Turkmenistan, Azerbaijan, and Iran), the Black Sea (bordering Russia, Ukraine, Georgia, Turkey, Bulgaria, and Romania), and the Sea of Azov (bordering Russia and Ukraine). According to unverified records, some individuals have reportedly

Figure 2. Beluga sturgeons caught on the River Tikhaya Sosna in Southern-Russia in 1921. The largest specimen on top weighted 1227, of which 225 kg was egg mass (source: https://www.gw2ru.com/lifestyle/2619-beluga-biggest-fish-russia).

reached up to 7-9 meters in length and weighed as much as 1-2 metric tons, making the Beluga sturgeon the largest freshwater-associated fish species. According to internet sources (see reference list) , some large individuals caught in the Caspian Sea weighted 1000-1200 kg. In 1970, an 800 kg female caught in the Volga delta contained 112 kg of eggs.

Today, specimens of this magnitude are virtually non-existing. The average size of individuals caught for commercial purposes is now between 80 and 150 cm in length, with weights of 20–30 kg.

Throughout the 20th century, these ancient, massive individuals disappeared from fisheries records, with overfishing considered the primary cause of their decline. The estimated total biomass of Beluga sturgeon in the Caspian Sea dropped from approximately 50,000 metric tons in the 18th century to just 10,000–15,000 metric tons by the 20th century. Despite declining annual catches, fishing pressure intensified, accelerating the population collapse. Today, Beluga sturgeon populations in Europe have either completely collapsed or persist in small remnant populations. The species is classified as "Critically Endangered" by the IUCN.

Sturgeon biology

Spawning migration

Spawning migrations are a fundamental aspect of the life history of all sturgeon species, as these anadromous fish move between marine and freshwater environments for reproduction. These migrations are complex and influenced by a variety of environmental and biological factors.

The transition from marine habitats into riverine systems is triggered by environmental cues such as changes in water conditions, river discharge, and photoperiod. Migration typically begins when river temperatures rise to between 13 and 20 °C, a seasonal shift usually occurring in spring and summer within the species› distribution range (Brosse et al., 2000; Kynard & Horgan, 2002). Increased river discharge, often resulting from snowmelt or heavy rainfall, serves as a key environmental trigger, as floods signal adequate oxygenation and nutrient availability in the river system (Rochard et al., 1990). Additionally, the gradual increase in daylight hours during spring induces hormonal changes that initiate gonadal maturation and spawning migrations (Smith, 1985).

Both Atlantic and European sturgeon exhibit *homing behaviour*, meaning they tend to return to their natal rivers to spawn, a trait shared with many anadromous fish. However, the strength and fidelity of this homing can vary between populations and species and is influenced by environmental factors and human pressures (e.g., habitat loss and stocking practices). Particularly the Atlantic sturgeon exhibits strong homing, as demonstrated through tagging, telemetry, and genetic studies. Genetic studies support natal homing in Atlantic sturgeon and have revealed distinct population structures corresponding to specific river systems (Wirgin et al 2000). Telemetry and tracking confirmed that mature Atlantic sturgeon return to their natal rivers during spawning seasons (Balazik et al 2017). Microsatellite markers demonstrated high fidelity to natal rivers across the U.S. Atlantic coast populations (Grunwald et al 2008).

Evidence of natal homing in European sturgeon is more limited due to the critically endangered status of the species and the near-total collapse of its natural populations. Nonetheless, historical and genetic evidence supports homing behaviour. Genetic differentiation among historical populations suggests natal philopatry (Ludvig et al 2002). Although active restocking is ongoing, reintroduction projects aim to reestablish natural homing and spawning behaviour (Williot et al 2011). Genetic evidence supports the idea that European sturgeon shows homing to natal rivers and suggests importance of preserving local stocks (Jenneckens et al 2000).

The spawning migration can be divided into several phases. The initial phase involves individuals leaving marine feeding grounds and migrating toward estuaries before continuing upstream toward spawning sites. Upon approaching these sites, sturgeon often pause in deep-water, low-current refuges to acclimate to local conditions. These holding areas serve as transitional zones where individuals may remain for days or even weeks before spawning occurs (Kynard et al., 2014).

Multiple navigation mechanisms assist sturgeon in locating their spawning grounds. Olfactory navigation enables them to detect and recognize the chemical signature of their natal river, a process known as homing (Bemis & Kynard, 1997). Hydrodynamic cues, such as variations in river flow and turbulence, further aid in site localization (Kynard & Horgan, 2002). Additionally, geomagnetic orientation, a mechanism well-documented in birds and fish, may play a role in long-distance navigation. Sturgeon, like other migratory species, possess magnetite crystals in specialized brain tissues, allowing them to detect and align with Earth's geomagnetic field (Rochard et al., 1990). This suggests that sturgeon use geomagnetic cues for orientation while navigating across vast marine environments.

The distance covered during spawning migrations can span several hundred kilometres, depending on the fish's marine foraging location, the length of the spawning river, and the specific location of the spawning grounds (Bemis & Kynard, 1997).

Spawning behaviour

Spawning behaviour in sturgeon is complex and influenced by both environmental conditions and the physiological state. Spawning occurs in freshwater, where both females and males play different roles in the reproductive process. Their behaviour is adapted to maximize the survival of eggs and larvae in fast-flowing river environments. Spawning sites are typically located in areas with gravel or rocky substrates, and spawning takes place in strong current zones. The eggs are adhesive to the substrate, initiating incubation.

Females typically spawn only once every 3–5 years, whereas males can spawn more frequently, often every other year. This difference is due to the higher energy investment required for egg production in females (Smith, 1985).

Prior to spawning, both males and females seek out fast-flowing areas with suitable substrate, such as gravel or small stones, which provide optimal conditions for egg attachment and oxygenation (Rochard et al., 1990; Kynard & Horgan, 2002). Spawning occurs during periods of low bedload transport and minimal sediment deposition, ensuring sufficient oxygen supply for incubating eggs (Rochard et al., 1990).

During the spawning act, the female releases eggs in batches, typically in mid-channel or deep sections of the river. A critical environmental factor is the hydraulic flow pattern, which must be strong enough to disperse fertilized eggs, but not so strong that they are carried away from the optimal incubation conditions of the spawning site. Downstream areas may be less suitable for incubation and hatching (Kynard et al., 2014). Female sturgeon can produce several hundred thousand to millions of eggs. After spawning, the female provides no parental care or further interaction with the eggs (Bemis & Kynard, 1997).

Males play an active role in spawning by closely following the female during the process. Eggs and sperm are released simultaneously into the water column, where turbulence and hydrodynamic conditions facilitate gamete contact and fertilization. Males often compete with one another for access to spawning females, and it is common for a single male to fertilize eggs from multiple females within the same spawning season. This strategy enhances genetic diversity and increases the chances of offspring survival (Rochard et al., 1990).

Genetic studies of fertilized eggs and larvae have shown that multiple males contribute to the fertilization of a single female's egg batch, indicating external group spawning with high sperm competition. Birstein et al (2000) found strong evidence of polyandry in wild sturgeon populations based on genetic analyses of embryos. King et al (2001) performed microsatellite DNA analysis and revealed multiple paternity in Atlantic sturgeon. This strategy likely enhances genetic diversity and reproductive success in species with relatively low spawning frequency.

Female sturgeons do not release all their eggs in a single event, but instead spawn in several batches (Detlaff et al 1993). This reproductive trait is termed "fractional spawning", a strategy that increases the chances of successful fertilization and egg dispersal, especially under fluctuating flow and temperature conditions. Bemis et al (1997) documented that females release their eggs over several hours in successive batches, which matches observations of both Atlantic and European sturgeon in natural and artificial conditions (Willot et al 1991).

Incubation, hatching, and early migrations

The eggs hatch within 4–7 days, depending on water temperature. For Atlantic sturgeon, the reported optimal incubation temperature is 17-20 °C, whereas the tolerable range is between 13 and 23 °C (Van Eenennaam et al 1996). For European sturgeon, the optimal incubation temperature is narrower. Dettlaff et al (1993) reported the optimal range between 15 and 18 °C, whilst the tolerance ranged from 12 to 20 °C. Willot et al (2000) found that egg development shows high mortality above 19 °C and delayed development below 13 °C. Newly hatched larvae remain within the substrate for the first few days as they absorb their yolk sac. Once the yolk sac is depleted, the larvae begin migrating towards more nutrient-rich habitats, such as estuaries, delta regions, or coastal waters (Kynard & Horgan, 2002).

Feeding ecology

Sturgeon are benthic generalists, feeding on a wide variety of bottom-dwelling organisms, including small fish, mollusks, crustaceans, and insect larvae. Lacking teeth, they rely on a suction feeding mechanism to ingest food. Sensory barbels located in front of the mouth help detect prey in the sediment. Upon detecting prey, the sturgeon rapidly opens its mouth, generating a vacuum that draws in both food and surrounding substrate. The fish then expels sediment while retaining and swallowing the prey (Bemis & Kynard, 1997).

Juvenile sturgeon begin life in freshwater, initially feeding on their yolk sac, which provides essential nutrients during the first few days post-hatching. As they grow, they transition to feeding on small planktonic organisms before shifting to a diet of larger benthic invertebrates (Scott & Crossman, 1973; Rochard et al., 1990). Depending on resource availability, juvenile sturgeon may also consume small crustaceans and fish larvae (Magnin, 1964). Typical prey items include polychaete worms, insect larvae, and small bivalves.

Adult sturgeon are benthic opportunists with a diet dominated by molluscs, such as clams and snails, which they locate using their flexible snout and specialized sensory organs while foraging in the sediment. Crustaceans, including crabs and shrimp, are also important dietary components, particularly in brackish and marine environments. While sturgeon primarily consume invertebrates, they occasionally feed on bottom-dwelling fish species and scavenged fish carcasses (Smith, 1985)

Growth and longevity

Historical records indicate that the Atlantic sturgeon was capable of reaching exceptional sizes. Slow growth rates are typically associated with long lifespans, and this species can live for over 60 years, with growth rates decreasing as individuals age. The largest documented specimen measured 4.3 meters and weighed 368 kg (https://www.havochvatten.se/arter-och-livs-miljoer/arter-och-naturtyper/storar.html?-utm_source=chatgpt.com). Another large individual, caught in North America, was recorded at 4.5 meters in length and weighed over 350 kg (Scott & Crossman, 1973). However, such old and exceptionally large individuals have always been rare (Magnin, 1964).

Causes of decline in Europe and the Nordic region

The primary threats to sturgeon populations over the centuries have been overexploitation, habitat degradation, and loss of connectivity due to hydropower development, which obstructs spawning migrations. Additional factors contributing to population decline include increasing pollution and climate change (Smith, 1985).

Overfishing and historical exploitation

Overfishing pressure has consistently exceeded the reproductive capacity of sturgeon populations, making it the most significant anthropogenic factor behind their dramatic decline. Intensive fishing, particularly with the advent of motorized fishing vessels, progressively reduced population sizes. Up until the 19th century, sturgeons in the Nordic region were primarily caught in rivers within the Baltic Sea drainage basin. In 1880, fishing expanded to coastal waters near the Elbe, and by 1885, to the Vistula River (Blankenburg, 1910). The development of diesel engines further enabled offshore trawling (Steiner, 1918).

Despite clear declines in catch numbers, the fishing industry of the 19th century remained largely unrestricted. Experts foresaw the devastating consequences of overfishing on sturgeon stocks (Heckel & Kner, 1858; Anonymous, 1895; Sterner, 1918), yet intensive fishing continued. As a result, fishing mortality increasingly targeted younger, immature individuals, and thereby accelerating population collapse.

Dams and river regulation

Hydropower dams and river regulation in European river systems have blocked spawning migrations and restricted access to historical spawning grounds. Many attempts to construct fish passages for sturgeon have proven ineffective. The regulation of river systems through dams, gates, sluices, and other hydraulic structures, created major disruptions to sturgeon habitats, and mitigation measures were largely inadequate.

Spawning migrations in the Elbe, Eider, Oder, Rhine, and Vistula rivers were heavily impacted by hydropower developments, regulated flow regimes, and water withdrawals. Additionally, riverbed dredging for navigation altered the physical structure of the habitats (Voigt, 1870; Kinzelbach, 1987).

The construction of the Volgograd Dam on the Volga River blocked Beluga sturgeon (Huso huso) from reaching its traditional spawning sites (Barannikova, 1995). The spawning area for Russian sturgeon (*Acipenser gueldenstaedtii*) in the Volga was reduced by 85%, while Sterlet (*A. ruthenus*) spawning grounds decreased by 40%.

A similar fate befell the European sturgeon population in the Guadalquivir River following the construction of the Alcalá del Río Dam and its associated reservoir (Rochard et al., 1990). Many of these dams obstructed both upstream and downstream migration, while juvenile sturgeon passing through hydropower turbines suffered high mortality, leading to recruitment failure.

In regulated river sections, minimum flow requirements were often insufficient, and variable discharge regimes from hydropower plants forced spawning-ready sturgeon to move downstream. This displacement led to resorption of eggs in females, further reducing reproductive success.

Pollution and water contamination

Chemical pollution from industry and agriculture has significantly increased sturgeon mortality, particularly in the Volga River.

For instance, a mass mortality event in the Volga River in 1965 was caused by industrial effluents near the city of Krasnoarmeisk, killing an estimated 350,000 individuals. In 1988, an oil spill in the lower Volga also led to extensive sturgeon mortality (Pavlov et al., 1994). In 1987, high concentrations of pesticides were detected in dead sturgeon juveniles from hatcheries in the Volga River.

Shipping traffic and electromagnetic interference

The increase in shipping traffic and electromagnetic fields from high-voltage power lines has further disrupted sturgeon migrations and spawning behaviour.

Since the mid-19th century, rising ship traffic has had a severe impact on spawning populations and larvae. Waves generated by large vessels have washed juvenile and spawning sturgeon ashore, leading to high mortality rates. These sudden wave surges have also caused mechanical destruction of benthic communities.

Additionally, electromagnetic fields created by power lines spanning rivers have been shown to interrupt sturgeon migration. Sturgeon frequently ceases their movements when encountering such areas (Pavlov et al., 1994).

Conservation measures for sturgeon populations

In recent decades, mitigation and restoration efforts have gained increasing attention across the entire range of sturgeon species. Successful reintroduction programs require long-term commitments to habitat management, continuous monitoring, and public awareness. Conservation efforts involve multiple strategies, including direct habitat improvements and increased awareness of the species' critical status:

- Fishing regulations: Stricter laws and fishing bans, such as those implemented in France (1982) and the former Soviet Union (1940), have proven effective in reducing fishing pressure on sturgeon populations.
- Spawning habitat restoration: The creation of artificial spawning sites and restrictions on destructive activities such as gravel extraction have helped mitigate habitat degradation.
- Aquaculture and restocking programs: Sturgeon breeding and stocking programs have shown mixed success but remain a promising conservation strategy. Reintroduction projects, such as those in Göta älv (Sweden) and the Oder River (Germany), aim to restore populations through captive breeding and juvenile releases (Friedrich et al., 2008).
- Public awareness: Educational campaigns have played a key role in increasing public understanding of the need for sturgeon conservation and have contributed to a reduction in illegal fishing activities.
- International collaboration: Several European countries, including Germany and the Netherlands, have initiated coordinated reintroduction efforts to restore endangered sturgeon populations.

Broader conservation efforts highlight that all extant sturgeon species are threatened, primarily due to historical overfishing for caviar, habitat degradation, and illegal trade. Current trade is largely dependent on aquaculture, yet the impact of captive-bred individuals on wild populations remains uncertain, especially regarding genetic integrity and disease transmission. These challenges underscore the importance of stringent CITES enforcement, comprehensive genetic monitoring, and coordinated regional conservation strategies to ensure the viability of sturgeon populations in both current and former range states, including the Nordic region (VKM, 2025).

Sturgeon in Sweden

The Atlantic sturgeon has been a natural part of Sweden's ichthyofauna for over 5,000–6,000 years, particularly along the west coast. Archaeological excavations along the Göta älv river have uncovered sturgeon scales in kitchen middens, indicating that the species was a popular food source as early as the Mesolithic period (Jägrud et al 2023).

Historically, sturgeon fishing in Göta älv played a significant role, particularly during the 16th, 17th, and 18th centuries. The species was recorded in several Swedish rivers, particularly those draining into the Baltic Sea or Kattegat.

Göta älv is one of Sweden's largest rivers, flowing from Lake Vänern into Kattegat at Gothenburg. As Sweden's most water-rich river, it has been crucial for navigation and fisheries between Vänern and Gothenburg. Historically, Göta älv was known for its rich fish stocks, including sturgeon, which supported local economies through traditional fisheries. From the 16th century onward, large sturgeon catches were documented, particularly where the river runs through Gothenburg. The largest recorded individual was caught around 1650, weighing over 150 kg (Jägrud et al 2023).

During the 17th and 18th centuries, much of the catch was sold to aristocratic households, and Gothenburg's fish market was famous for its fresh sturgeon. However, throughout the 19th century, catches became increasingly sporadic, and by the early 20th century, it became evident that the species had disappeared from the river system.

In the past, sturgeon fishing in Göta älv was unregulated, leading to overexploitation. The slow growth and low reproductive rate of the species made it particularly vulnerable to intensive fishing. Combined with increasing river modifications and pollution, these pressures ultimately led to the extirpation of sturgeon from Göta älv (Jägrud et al 2023).

In recent years, efforts have been made to reintroduce the Atlantic sturgeon to Swedish waters. In June 2024, a significant milestone was achieved when 100 juvenile Atlantic sturgeons were released into the Göta älv River as part of a 10-year reintroduction project. These juveniles, bred in Germany, were equipped with acoustic transmitters to monitor their movements and adaptation to the new environment (Phys.org, 2024). The project, named "Störens återkomst" ("The Return of the Sturgeon"), is a collaborative effort involving the Swedish Anglers Association, the University of Gothenburg, the Swedish University of Agricultural Sciences (SLU), and the Gothenburg Museum of Natural History. The initiative aims not only to restore the sturgeon population but also to enhance the ecological balance of the river system (The Local, 2024).

Current reintroduction efforts

After over a century of absence, efforts are now being made to reintroduce the Atlantic sturgeon to Swedish waters. Since the 1990s, approximately six million juvenile sturgeons have been released into the Baltic Sea. These individuals have since been observed migrating throughout southern parts of the Baltic, with some reaching as far north as Bothnian Bay.

As part of the project, juvenile sturgeons have been released, marking the beginning of reintroduction efforts in the river system. They were tagged with acoustic telemetry transmitters to monitor their movements and habitat preferences. The long-term goal is to continue restocking efforts in Rivers Göta älv and Nordre älv, aiming to establish a self-sustaining population over time. This process is expected to take at least 50 years.

Historical sturgeon occurrence in other Swedish rivers

- Dalälven: A large river flowing into the Baltic Sea, with historical records of sporadic sturgeon catches, suggesting its potential role as a spawning river for Baltic sturgeon.
- Norrström: Originating from Lake Mälaren, it flows through Stockholm into the Baltic Sea (Saltsjön). Historical accounts from the 16th and 17th centuries describe sturgeon fisheries, indicating its economic importance at the time.
- Helge Å: Draining into the Baltic Sea through Skåne, there are sporadic records of sturgeon bycatch, though its significance as a spawning river remains uncertain.
- Emån: A river in Småland flowing into the Baltic Sea, with medieval records of sturgeon catches, though there is no evidence of established sturgeon fisheries in the system.

Sturgeon in Finland

Sturgeon have historically been part of the fauna of Finnish rivers, particularly in the Kymmene River (*Kymijoki* in Finnish). Archaeological evidence suggests that sturgeon was present in Finnish waters and river systems for several millennia. In addition to the Kymmene River, it is possible that other rivers, such as the Vuoksi and Torne River (*Tornionjoki*), also supported sturgeon populations, though records indicate that both the populations and fisheries in these rivers were less significant (Ludwig & Gessner, 2007).

Sturgeon was historically a valued food source in Finland, and sturgeon fisheries played a role in the local economy and culture. However, overfishing, habitat degradation, and dam construction, which obstructed spawning migrations, contributed to a drastic decline in Finnish sturgeon populations. Today, the Atlantic sturgeon is considered functionally extinct in the Baltic Sea and its former spawning rivers (Jansson & Haldin, 1988).

Interest in restoring sturgeon populations in the Baltic Sea has been growing. International collaborative projects focus on habitat restoration, removal of migration barriers, and reintroduction efforts in former sturgeon habitats. These measures may, over time, lead to the re-establishment of sturgeon in Finnish rivers (Lehtonen & Toivonen, 1988).

Sturgeon in modern Norway

Sturgeon is now rare in Norwegian marine waters. Historically, they were occasionally caught as bycatch along the Norwegian coast (VKM 2025). Unlike in Sweden and Finland, there is no documented evidence of sturgeon being caught or observed in Norwegian rivers.

However, over the past two centuries, there have been some recorded captures of sturgeon along the Norwegian coast and in fjords (Figure 3). These catches are probably episodic natural dispersal or escapees linked to reintroduction programs in the Baltic region (VKM, 2025). The species is therefore regarded as a rare visitor that may occasionally appear in fisheries bycatch. According to available sources from Artsdatabanken, documented Atlantic or European sturgeon catches in Norwegian waters date back to the late 19th or early 20th century. It is likely that these specimens were both Atlantic and European sturgeons. Figure x shows a map of recorded catches of sturgeons on the Norwegian coast (Figure 4).

Possible reasons for the absence of sturgeon catches in medieval and modern times

The lack of recorded sturgeon catches in medieval and modern times in Norway may be attributed to a combination of geographical and ecological factors. Both Atlantic and European sturgeon have specific habitat requirements, one of the most critical being large river systems that provide access to suitable spawning grounds and facilitate migration between freshwater and nutrient-rich estuaries, fjords, and marine environments.

Norwegian anadromous rivers are generally shorter and colder compared to the major European river systems that historically supported established sturgeon populations, such as the Loire, Rhine, and Danube. In western Norway, steep rivers originate from high-altitude catchment areas, often fed by glacial meltwater. The low summer water temperatures in these systems likely prevented the successful establishment of sturgeon populations.

In contrast, coastal rivers in eastern and southern Norway, as well as the anadromous rivers of Trøndelag, generally have warmer waters and lower-elevation catchments. These rivers would have presented the most favourable conditions for sturgeon occurrences in Norway. However, it is worth noting that even in Sweden and Finland, only a few large river systems supported stable sturgeon populations and fisheries, indicating that large, temperate rivers alone were not sufficient for sturgeon establishment. It is likely that a complex interplay of physical and biological environmental factors determined which rivers were suitable for spawning and juvenile development.

Current scientific knowledge does not allow for a detailed analysis of these historical habitat conditions, particularly given the climatic fluctuations of the medieval period. The Medieval Warm Period (900–1300 AD) was followed by the Little Ice Age (1300–1800 AD), and these climate shifts likely had a significant impact on sturgeon distribution during this time. Throughout this period, sturgeon populations likely experienced more favourable conditions in southern and central European river systems, as well as in the Baltic Sea River basins, where temperatures were more stable and suitable.

Despite this, it remains plausible that sturgeon may have occurred in some of Norway's

Figure 3. Sturgeon caught on the Norwegian coast at Sola. Picture is taken at Vågen fish market (Photo: Hans Henriksen / Stavanger Byarkiv).

larger river systems, particularly in regions where the most temperate rivers discharge into fjords or directly into the sea. Although the species is now extremely rare in Norwegian waters, several historical catches have been reported from coastal and fjord environments.

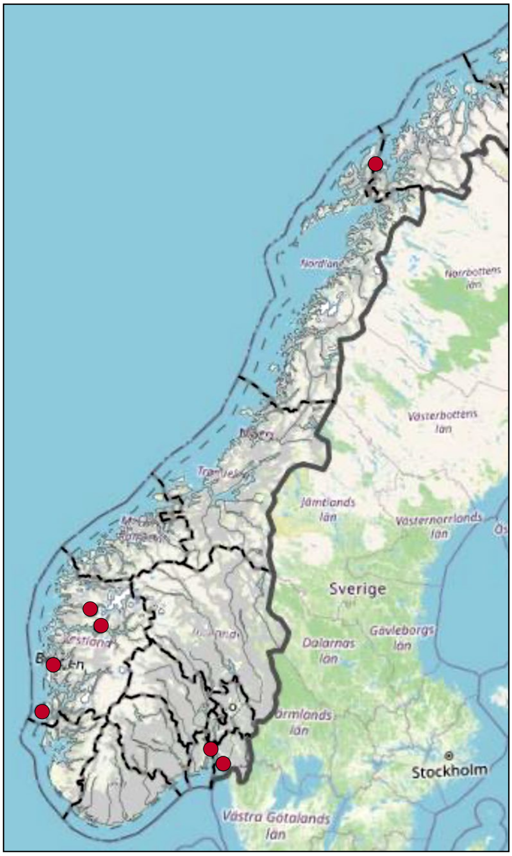

Figure 4. Recorded sturgeon catches on the Norwegian coast (source: Artsdatabanken.no)

This suggests that sturgeon may have historically used some of Norway's largest and most accessible rivers as spawning and nursery areas, with delta regions potentially serving as feeding grounds.

Sturgeon in historical Norway: Ecological plausibility

Based on ecological and biological considerations, it is plausible that Atlantic sturgeon and/or European sturgeon may have historically occurred in certain Norwegian rivers during various climatic periods, particularly before the medieval era. This hypothesis is supported by the presence of suitable habitat characteristics in several Norwegian rivers, which align with known sturgeon spawning and nursery requirements (Gessner & Bartel, 2000; Sulak & Clugston, 1999).

Ecological suitability of Norwegian rivers for sturgeon

Sturgeon are anadromous fish that migrate from marine environments into freshwater rivers to spawn. Their spawning success is closely tied to specific riverine conditions, including:

- River size and discharge:
  Large rivers with substantial discharge provide the necessary flow conditions for sturgeon migration and spawning (Gessner & Bartel, 2000). For instance, the Glomma River, Norway's longest and most voluminous river, offers extensive freshwater habitats that could have supported sturgeon populations.
- Substrate composition:
  Sturgeon prefers spawning over clean, hard substrates such as gravel and cobble, which facilitate egg adhesion and development (Gessner & Bartel, 2000). Rivers Numedalslågen and Drammenselva have sections with suitable substrates that may have served as potential spawning grounds.
- Flow velocity and oxygenation:
  Optimal spawning occurs in areas with moderate to strong flow velocities (0.4–2.0 m/s), ensuring well-oxygenated conditions essential for egg and larval development (Sulak & Clugston, 1999). Sections of the aforementioned rivers exhibit such flow characteristics, especially during spring melt periods.
- Temperature regimes:
  Spawning typically takes place when water temperatures range between 13°C and 22°C (WWF, 2018). Norwegian rivers experience such temperatures during late spring and early summer, aligning with sturgeon spawning periods observed in other parts of Europe.
- Estuarine access:
  The presence of estuarine zones at river mouths, such as those found in the Oslofjord and Skagerrak regions, provides critical transitional habitats for juvenile sturgeon before they migrate to marine environments (NOAA Fisheries, 2021).

During warmer climatic periods, such as the Holocene Thermal Maximum, river temperatures and flow regimes in Norway would have been more conducive to sturgeon spawning and development. These periods could have facilitated the northward expansion of sturgeon populations, allowing them to exploit suitable habitats in Norwegian rivers (Nikulina & Schmölcke, 2016).

While direct evidence of historical sturgeon populations in Norwegian rivers is lacking, the ecological characteristics of several rivers align with known sturgeon habitat requirements. Combined with favourable climatic periods in the past, it is reasonable to speculate that sturgeon may have utilized these rivers and estuaries for spawning or feeding. Further research, including archaeological investigations and genetic studies, could provide more definitive insights into the historical presence of sturgeon in Norwegian fiords and rivers.

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