Dying for a canape: The welfare implications associated with both traditional and 'ethical' production of caviar from sturgeon

Helen Lambert[1*], Sophie Becker[2], Wasseem Emam[3]

[1]Animal Welfare Consultancy, United Kingdom, [2]New York University, United States, [3]Ethical Seafood Research, United Kingdom

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Scope Statement

This review covers a neglected yet growing welfare issue in aquaculture and is especially relevant to the Aquatic Animals' Welfare: Current Issues in Fishery and Aquaculture. The farming of sturgeon to produce caviar is increasing globally, even though little is known about the welfare implications of aquaculture for these unique, long-living, and large animals. The use of nonlethal methods for egg harvesting is increasing as these methods are thought to offer a more ethical alternative to traditional methods where the female is killed. However, these 'nonlethal' methods raise significant welfare concerns and could potentially perpetuate suffering. Consequently, there is an urgent need for significant exploration and research into this field.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

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Helen Lambert: Data curation, Writing – original draft. Sophie Becker: Data curation, Writing – review & editing. Wasseem Emam: Conceptualization, Writing – review & editing.

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Abstract

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Abstract

The farming of sturgeon to produce caviar is increasing globally, even though little is known about the welfare implications of aquaculture for these unique, long-living, and large animals. The use of nonlethal methods for egg harvesting is increasing as these methods are thought to offer a more ethical alternative to traditional methods where the female is killed. However, these 'nonlethal' methods raise significant welfare concerns and could potentially perpetuate suffering. Consequently, there is an urgent need for significant exploration and research into this field.

This review presents and discusses some of the welfare concerns associated with producing caviar from sturgeon, including the traditional and nonlethal methods of egg harvesting and the concerns associated with rearing them in aquaculture systems.

1. Scope of caviar production

All 27 species of sturgeon are listed in the appendices of the CITES treaty, highly restricting the fishing of wild individuals due to their worsening conservation status (CITES, 2002). Wild populations have declined as a result of both legal and illegal overfishing and as a result of significant habitat fragmentation and loss (Scarnecchia et al., 2014; Stokesbury et al., 2014; Tavakoli et al., 2021; Wu et al., 2019). Meanwhile, the demand for caviar, and to a lesser extent meat, from sturgeon species has continued to grow, and so to cope with demand, aquaculture production has risen globally (Bronzi et al., 2019; Tavakoli et al., 2021). Farming sturgeon for caviar is still relatively new, as before 1997, when CITES protected all sturgeon species, nearly all sturgeon were wild-caught (Tavakoli et al., 2021).

Around 17 different sturgeon species are recognised for caviar production, and a further four hybrids and two Polyodontidae species are also used (Bronzi and Rosenthal, 2014). China is the number one exporter of caviar, followed by the USA, Italy, France and Germany (Raposo et al., 2023). Global production is estimated at around 700 tons of caviar (Degani and Yom Din, 2022).

Originally, most caviar was produced from sturgeon fished in the Caspian Sea. However, today, nearly all caviar comes from aquaculture (Tavakoli et al., 2021). Furthermore, many of the countries now producing caviar had no prior involvement in the industry, leading to both a diversification of the quality of products but also varying regulations and standards regarding welfare and best practices (Bronzi et al., 2019; Tavakoli et al., 2021).

The aquaculture systems used for caviar production vary depending on the life stage, the farm, and the geographical location. For instance, running water ponds and cage farming are the most commonly seen systems for sturgeon farming in China. However, extensive systems and recirculating aquaculture systems (RAS) are popular for caviar, with the latter increasing in recent years (Yang et al., 2018). Elsewhere, ponds, cages and RAS may all be used for sturgeon farming, with separate facilities or holdings corresponding with the different life stages (Chebanov and Galich, 2013).

2. Welfare implications of caviar production in aquaculture

Sturgeon are slow to mature, which means that young sturgeon can take 7-10 years to produce eggs (Raposo et al., 2023). During this time, the rearing environment, husbandry practices and procedures can all impact the farmed fish's welfare. Then, once they are sexually mature and producing eggs, the females are either killed or have their eggs harvested using a variety of nonlethal techniques, which can introduce significant welfare concerns.

2.1. Egg harvesting

Traditionally, sturgeon are typically killed before egg harvesting, and although the method of killing is relevant from a welfare perspective, the process of egg harvesting is generally not, as it is performed on a dead fish. Traditional methods are considered optimum in terms of egg quality. However, as the fish is killed, it is also unsustainable, especially when considering it can take a decade for females to reach sexual maturity. Furthermore, significant concerns exist regarding the typical stunning and killing methods used for sturgeon (Clemente et al., 2023; Williot et al., 2018).

In response to the concerns over sustainability and ethics, there has been a rise in efforts to use nonlethal methods of egg harvesting so that the same fish can be used to produce multiple batches of eggs. Nonlethal methods for caviar collection can pose considerable short and long-term welfare concerns, and mortalities are an inherent risk (Bani and Banan, 2010; Tavakoli et al., 2021).

Nonlethal methods vary in the degree of invasiveness, from caesarean sections performed under general anaesthesia through to non-surgical methods where the fish is massaged. Nonlethal methods are typically used in combination with hormone therapy to induce labour artificially so that the female releases the eggs before being stripped (Raposo et al., 2023; Tavakoli et al., 2021). This produces ‘ovulated caviar’, which usually has to be labelled as such, as the eggs have to undergo artificial treatment to prevent them from swelling and water-hardening, which is not necessary with traditionally harvested caviar (Bronzi and Rosenthal, 2014; Chapman, and Van Eenennaam, 2016). Caviar produced using nonlethal methods may also be marketed as “no-kill caviar, " intended to promote a more sustainable and ethical product (Stephen, 2022). However, there are significant welfare concerns associated with nonlethal methods of caviar harvesting, which have been largely neglected by the scientific literature.

2.1.1. Caesarean section

Caesareans are the most invasive of the nonlethal methods of caviar harvesting and require the fish to be placed under general anaesthetic. The method is typically used for very large individuals, as other less labour-intensive and invasive methods are preferred for smaller fish (Chebanov and Galich, 2013). The procedure involves an open laparotomy, which is an incision of between 8-14cm long into the abdomen so that the ovulated eggs can then be extracted. The fish is then sewn up using silk or kapron-coated thread and monitored for a few weeks (Chebanov and Galich, 2013).

In addition to handling (see section 2.1.5.2), sturgeon undergoing caesareans experience other welfare issues as a result of the procedure, including from the general anaesthetic. Anaesthetics are widely used on fish to avoid stress during certain procedures, and some studies suggest they can successfully reduce stress caused by confinement and handling (Zahl et al., 2012). However, there are also indications that the anaesthetic itself may also induce a stress response in fish (Zahl et al., 2012). For example, in Siberian sturgeon, the anaesthetics MS-222 and clove oil induced a stress response.

However, clove oil was considered to have better results, providing optimum concentrations were used (Feng et al., 2011).

Mortality rates following caesareans can also be high, depending on the aftercare, the skills of the operator, and the condition of the fish. Furthermore, suturing sturgeons can be difficult, and even professionals invariably pull through the musculature (Mims et al., 2004). In addition, muscular stress on the incision can result in the sutures rupturing (Aramli et al., 2014). As a result, mortality rates have been reported to be higher than 75% in paddlefish (Mims et al., 2004) but as low as 10% for beluga sturgeons and 15% for Russian sturgeons (Chebanov and Galich, 2013).

2.1.2. Key-hole surgery

A common non-lethal method that is used to harvest the eggs is the use of a small incision into the abdomen, which can be performed whilst the fish is conscious, rendering it less labour-intensive than a caesarean section. This method has been widely used since 1986 and reportedly has low mortality rates (Chebanov and Galich, 2013; Parandavar et al., 2006; Podushka, 1999, 1986).

A scalpel is used to open the female's abdominal cavity to create a small incision, ranging from anywhere between 1cm-8cm, depending on the size of the fish (Bani and Banan, 2010; Chebanov and Galich, 2013; Parandavar et al., 2006). The eggs are then manually stripped through this incision by massaging the abdomen whilst the incision is kept open (Chebanov and Galich, 2013). The female may be conscious during this process, as general guidance only suggests sedating the larger females for ease (Chebanov and Galich, 2013). The stripping process may be repeated once or twice until all the eggs are removed. According to the 'Sturgeon Hatchery Manual, suturing of small 1-2cm incisions is unnecessary, as there is no increase in mortality risk, even when the kidney or blood vessels of the rectum are damaged in the process (Chebanov and Galich, 2013). Although this manual is over ten years old, the approach is still widely applied (Leavitt, 2022) and does not account for the fact that these sentient beings can feel pain and suffering from the procedure and potentially for the following days. Larger incisions are usually sutured, which is considered the most challenging part of the process due to dermal denticles in the sturgeon's skin (Chebanov and Galich, 2013).

The procedure is considered to be efficient, taking, on average between 5-17 minutes per fish, depending on the size of the female (Bani and Banan, 2010). This is equal, or shorter than the time needed for traditional harvesting, where the fish is killed first, and is faster than the caesarean method, which typically takes 30 min per fish, plus suturing time (Bani and Banan, 2010; Mims et al., 2004).

Overall, the procedure is considered low-risk, as the risk of serious infection is minimised, as is the risk of mortality from handling stress due to the shorter handling period (Bani and Banan, 2010; Mims et al., 2004). However, there are still risks, as mortalities result when the fish fail to feed following the procedure or are exposed to poor conditions (Bani and Banan, 2010; Parandavar et al., 2006). Furthermore, there has been little to no investigation into the welfare impacts of this procedure, especially when anaesthesia is not used, and poor feeding may, for example, result from long-term pain and distress in the fish. As far as we are aware, there is no mention of pain relief in the literature when discussing these procedures, and so although the procedure may not be fatal, it may still inflict suffering, pain and distress on the fish involved, and this may be long-lasting as the incision heals.

2.1.3. Non-surgical methods

Non-surgical methods, where the fish are massaged to remove the eggs without incisions, are considered less efficient, more labour intensive, and result in a poorer quality of eggs (Chebanov and Galich, 2013; Leavitt, 2022).

There has been little attention given to the welfare implications of this method with sturgeon in the scientific literature, and consumers could be led to believe that this method is the most humane one of all, as the fish are not killed or cut. However, stripping eggs in other fish species is known to be a significant stressor, not only because they must be handled, usually out of the water (see section 2.1.5.2), but the process itself can cause skin injury and considerable stress (Broom, 2007; Conte, 2004). Stripping the female of her eggs requires considerable manipulation, and research is required to explore both the short and long-term effects on welfare.

2.1.4. Traditional methods

Traditionally, sturgeon are killed for their eggs, which is considered to produce the highest quality of eggs, as no artificial hormone stimulation is required (Chebanov and Galich, 2013). Although the egg collection process is not a welfare concern, as the fish is already dead, the stunning and killing method is highly relevant. Methods are likely to vary depending on whether the sturgeon are wild-caught or farmed, with the former being a rarer occurrence due to CITES restrictions, although illegal fishing is a significant issue (Bronzi and Rosenthal, 2014; Raposo et al., 2023).

Percussive stunning and electronarcosis are recommended by the WOAH and EFSA (EFSA, 2004; WOAH, 2023) and, along with ice slurries, are commonly used on farms for slaughtering sturgeon (Williot et al., 2018). However, farms vary considerably in terms of how they perform the method. For example, the type of instrument used for percussive stunning, whether or not the fish is removed from the water, and the operator's skills can all significantly impact the fish's experience (Clemente et al., 2023). Furthermore, even though sturgeon are very different in behaviour and size from other farmed fish species, there has been little scientific research into slaughter methods for them (Williot et al., 2018). Consequently, there are no specific and validated indicators for monitoring unconsciousness in sturgeon (Clemente et al., 2023).

2.1.5. Overarching welfare issues associated with egg harvesting

2.1.5.1. Fasting

Prior to no-kill egg removal and prior to stunning and slaughter, farmed sturgeon may be fasted to empty their guts. Research indicates that long-term fasting significantly increases oxidative stress, weakens immunity, and increases mortality risk (Feng et al., 2011a). However, short-term fasting of less than two days may be less problematic for sturgeon (Cai et al., 2017). In particular, juvenile sterlet sturgeon (*Acipenser ruthenus*, Linnaeus 1758) only show significant effects on their swimming efficiency when fasted for over two days (Cai et al., 2017). Furthermore, starvation appears to suppress cortisol stress responses in juvenile great sturgeon (*Huso huso*) when captured and handled (Poursaeid and Falahatkar, 2022). However, despite the handful of studies in this area, much more needs to be done, not only to account for the different species of sturgeon farmed for caviar but also to explore the effects on mature individuals and the impact not only on their physiological and metabolic indications of welfare but also on their subjective states.

2.1.5.2. Capture and handling

Sexually mature sturgeon are large fish, so for ease, many farmers will seek to anaesthetise individuals before egg harvesting to immobilise or sedate them (Williot et al., 2018). As already discussed, anaesthesia may be aversive to the fish, representing a welfare concern (Williot et al., 2018). However, without it, the experience of being kept out of the water and handled by humans is a significant welfare concern for fish, resulting in considerable distress and potential pain and injury (Broom, 2007; Conte, 2004; Simide et al., 2018; Williot et al., 2018).

Although studies have found that sturgeons appear to be more resistant to handling stress, compared with most teleost species, they still show elevated levels of stress following handling, which can negatively affect their mental and physical welfare (Falahatkar et al., 2009; Falahatkar and Poursaeid, 2013). For instance, Great Sturgeon show elevated plasma cortisol levels following handling, with peak levels recorded 6 hr after handling and significant increases in plasma glucose levels recorded at 3hr after handling (Falahatkar and Poursaeid, 2013). However, further exploration is needed as cortisol levels can vary depending on the time of day, the technique used, how long the fish is handled, and whether they are exposed to other stressors (Simide et al., 2016). For instance, cortisol levels appear to vary in sturgeon who have been kept at different densities, with those kept at high densities showing greater stress responses when handled (Falahatkar et al., 2009).

Catch and release studies of wild white sturgeon (*Acipenser transmontanus* Richardson, 1836) also show that capture stress can significantly impact the fish (McLean et al., 2019). In particular, individuals showed reduced activity following release, and tagged sturgeon were found to gravitate towards the shore, indicative of a potential refuge-seeking behavioural strategy for recovery (McLean et al., 2019).

2.2. Rearing sturgeon for caviar

Sturgeon fish are a unique group of fish in many ways. They grow far larger than other species typically seen in aquaculture production, can live much longer, and show complex behaviours (Chebanov and Galich, 2013; Clemente et al., 2023). Despite sturgeon being around since the dinosaurs, we still know surprisingly little about them, an issue that has become more pressing since their increasing popularity in aquaculture. In addition to the egg harvesting processes, sturgeon must be reared for 6-10 years before they are mature enough to produce eggs. Their welfare during this time is of utmost importance, and like with other aquaculture species, they are susceptible to several factors that can improve or worsen their welfare. The main, overarching concerns of aquaculture production and the impacts on sturgeon are summarised below.

2.2.1. Water quality parameters

As with all farmed fish species, water quality and associated factors, such as levels of dissolved oxygen and temperature, are critical in ensuring the well-being of farmed sturgeon. Furthermore, maintaining stable conditions is also paramount for sturgeons, as variations can negatively affect their welfare.

Sturgeons have a limited capacity to adapt to hypoxia, both behaviourally and physically, as evidenced by the fact that their basal metabolism, growth, feeding and survival rate are all negatively impacted when exposed to changes in oxygen levels (Secor and Niklitschek, 2002). However, there are notable species differences. For instance, the Siberian sturgeon has a higher tolerance for hypoxic conditions than other species (Secor and Niklitschek, 2002). Nevertheless, oxygen is critical for the welfare of farmed sturgeon, and insufficient supply can negatively impact growth rates by as much as 20-43%, as well as causing increased stress levels and even suffocation and mortality in some individuals (Nonnotte et al., 2018b).

Temperature requirements vary according to the sturgeon's age, life stage, body condition, and the time of year, as sturgeon are typically exposed to lower temperatures over winter (Chebanov and Galich, 2013). Temperature can influence the time taken for sturgeon to mature and produce eggs, and critically, can impact their physical welfare. For instance, water that is too warm can result in lowered immunity and higher mortality rates in sturgeon (Mai et al., 2014; Wang et al., 2023). Furthermore, Siberian sturgeon lose the ability to stay upright (loss of equilibrium) in temperatures of 33°C and show metabolic changes indicative of stress (Wang et al., 2023).

The concentration of toxins such as ammonia, nitrite and nitrates can also negatively impact the welfare of farmed sturgeon and can be exacerbated by factors such as crowdedness and confinement. Systems that recirculate water are increasing in popularity but pose the risk of giving rise to unhealthy levels of toxins. Sturgeon vary in their tolerance to such toxins, with younger fish typically being less resistant (Salin and Williot, 1991). Sturgeon cannot control their ammonia uptake, which means that managing ammonia concentration is critical for their welfare and survival (Nonnotte et al., 2018a).

In response to nitrite toxicity, juvenile Siberian sturgeons show changes in behaviour, including increased breathing rate, erratic swimming, and a loss of equilibrium (Gisbert, 2018). Sturgeon also become more sensitive to nitrate as they age, and females show elevated levels of plasma glucocorticoids and plasma sex steroids in response to 30 days of exposure to 50mg/L nitrates (Hamlin et al., 2008). This is concerning because 50mg/L is considered an acceptable and average concentration in aquaculture (Hamlin et al., 2008). Nitrate toxicity can also cause anaemia in Siberian sturgeons (Williot et al., 2018).

2.2.2. Population density

The density at which sturgeon are kept, can positively or negatively affect other welfare concerns, including the water quality, disease prevalence, and their ability to behave normally. Furthermore, population densities also affect physiological well-being and development in sturgeon. For instance, high densities (12.68 kg m^2) were found to negatively affect the growth rate, stress, and immune responses in juvenile Chinese sturgeon, compared with low (4.80 kg m^2) and medium (8.99 kg m^2) densities (Long et al., 2019). Similar findings were found with juvenile hybrid sturgeon in RAS, where high densities (12kg/m^2) were found to negatively impact growth performance and welfare indicators because of chronic stress. In addition, in Siberian sturgeon, high densities (40kg/m^2) are thought to negatively impact reproductive development and increase the prevalence of infertility in females (Barulin, 2022).

The density in which sturgeon are reared in commercial farms is likely to vary depending on the life stage of the fish and the system used. In Chinese cage farms, densities are typically between 35-40 kg/m^2, then 50 kg/m^2 in RAS, and between 25-30 kg/m^2 in running water ponds (Yang et al., 2018), all of which are above the threshold that is known to result in welfare concerns in a range of sturgeon species.

2.2.3. Diseases

Farmed sturgeon are susceptible to a range of health concerns and diseases, and the prevalence of these are often impacted by other variables, including population densities, diet, and water quality (Ciulli et al., 2016; Radosavljević et al., 2019). Furthermore, the stressful procedures of egg harvesting may also result in compromised immunity, increasing disease prevalence.

The sturgeon nucleocytoplasmic large DNA virus (NCLDV) is commonly seen in farmed sturgeon (Mugetti et al., 2020). It can cause symptoms of anorexia, lethargy, lighter skin colouration, ulcers and lesions on the dorsal fin, gill damage, pale organs, and marbled liver (Ciulli et al., 2016). NCLDV is also associated with a mortality rate of around 50% (Ciulli et al., 2016). The white sturgeon iridovirus (WSIV) and the Acipenserid herpesvirus 2 (AciHV-2) are also significant pathogens as they can cause up to 95% mortality and considerable suffering in juvenile sturgeon (Radosavljević et al., 2019).

2.2.4. Behaviour

In the wild, Siberian sturgeon are typically benthic from 4 days of age and have relatively low mobility (Gisbert, 1999; Gisbert et al., 1999). This behaviour tends to be altered in aquaculture systems, as sturgeon reared in farms show a higher preference for swimming in the middle and upper areas of the tank and may even show inverted swimming patterns, which in the wild would make them more susceptible to predation (Gebauer et al., 2021). Such behaviours are often signs of weakness, physical stress, or starvation in fish and have been seen in various sturgeon species (Kasumyan and Kazhlayev, 1993; Ross and Bennett, 1997). However, it may also be an adaptation to the lack of predators in aquaculture (Gebauer et al., 2021). The changes seen in the behaviour of farmed sturgeon, compared with their wild-living counterparts, raise potential issues for conservation restocking efforts, as survivability is consequently often low (Gebauer et al., 2021; Wassink et al., 2022) but may also be indicative of subjective welfare concerns as a result of captivity. Further research is required to explore this.

3. Conclusion

This review has summarised the key welfare concerns regarding the methods used for extracting eggs from sturgeon and the factors influencing their welfare during rearing. Although the concerns regarding rearing are not necessarily unique to sturgeon, their responses and experiences on farms are. Until relatively recently, sturgeon were not farmed for caviar, and were only wild-caught, so caviar farming is new to both the humans and the fish. Therefore, given the unique nature of this group of species, the most likely challenge to their welfare will be the fact that these wild species of fish are being farmed in artificial environments, under controlled conditions, far removed from their wild habitat.

Little attention has been paid to the welfare of sturgeon in caviar production, which is concerning as they are not only kept in captivity for years, but the procedures they undergo during egg harvesting can be severe. Therefore, the longevity and severity of the welfare concerns of caviar production render this subject as one requiring further attention from welfare scientists and policymakers. This is ever the more critical, considering that consumers are being marketed ‘no-kill’ caviar as a more ethical choice, when such a product may actually be perpetuating suffering.

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