EXTENSION BULLETIN

NON-PENETRATIVE CAPTIVE BOLT

An Effective Method of Slaughter for White Sturgeon (*Acipenser transmontanus*)

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WESTERN REGIONAL AQUACULTURE CENTER

Photo: Courtesy of Jennifer Bowman

Adult white sturgeon broodstock swim near the water's surface.

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Front cover photo: Jackson Gross

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Introduction

Sturgeon (*Acipenser* spp.) are the largest freshwater fish in North America. They have an average lifespan of 50–60 years, making them some of the longest-living fish on earth. Several sturgeon species are raised and harvested for meat and egg production. The eggs get processed into caviar, one of the highest-value products in aquaculture.[1] White sturgeon (*Acipenser transmontanus*, Figure 1) is the most commonly raised species of sturgeon in aquaculture and is predominantly farmed in California and Idaho.[2]

Currently, there are no guidelines or regulations to manage the welfare of these fish during harvest.[3] Due to the diversity of size and anatomy of farmed fish, producers lack significant information regarding safe and humane harvest practices.

Common harvest protocol is a two-step process that uses manual percussion to cause incapacitation, followed by exsanguination in an ice bath as a termination step. Blunt-force trauma is a common percussive method used across U.S. fish farms. Manual percussive stunning requires precision and training to be effective; it can result in immediate loss of consciousness when performed correctly.[4,5] This process involves removing the fish from the water, placing it on a flat surface, and striking it in the approximate area of the brain with a tool, often a club or a fish priest (Figure 2).

However, the anatomy and physiology of sturgeon make the harvest process a unique challenge for farmers, as their large size, cartilaginous skeleton, and sharp scutes can make them especially difficult to handle. Cartilage is a flexible but strong connective tissue, and sturgeon are equipped with a thick plate of cartilaginous tissue at the top of the skull that protects the brain. As a result, effectively rendering a sturgeon unconscious is difficult, as generating the force needed to stun sturgeon effectively is challenging, and the target of the strike is small compared to the size of the head. Unlike many other species of sturgeon, white sturgeon skulls have a filled interfrontal space, which may

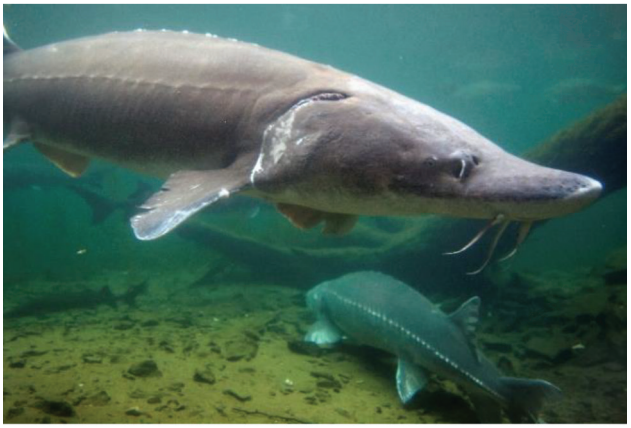

Photo: milehightraveler, Shutterstock

Figure 1. An adult white sturgeon.

Photo: Jackson Gross

Figure 2. A fish priest, commonly used as a first-step method in the harvest process.

contribute to the large amount of force needed to render the fish insensible.[4] Often, manual percussion requires multiple strikes before insensibility occurs.

For a slaughter process to be considered humane, insensibility should be reached within one second of a stunning application and maintained until death.[5] Establishing a more effective and humane slaughter protocol is essential for ensuring sturgeons' welfare during harvest and protecting farmers during processing. Non-penetrative captive bolt (NPCB) guns are devices that are powered by compressed gas and use a retractable bolt to deliver a fast, powerful percussive stun to an animal's head and are often used in food animal slaughter facilities.[6] A recent study suggests that using a Jarvis HPS-1 non-penetrative captive bolt can be an effective method for rendering juvenile and adult sturgeon insensible and maintaining insensibility throughout the remainder of the harvest process.[7]

Steps to Maximize the Effectiveness of NPCB Stunning

Standardization of strike pressure and precise bolt head placement by trained professionals can reduce the risk of requiring additional strikes. When possible, staff should prioritize fish and captive bolt positioning versus speed to ensure the accuracy and precision of the strike when fish are dewatered, ultimately leading to improved fish welfare.

NPCB Stunning Steps

1. Check equipment to ensure everything is clean and working correctly before starting.
2. Position the fish so its head is flat against a sturdy and hard surface and out of the water. Fish can be dewatered or remain in water with the head out of water on a hard surface.
3. Ensure the ventral (oral) side of the head is laid flush against the surface, as any space under the head will reduce the amount of force transferred.
4. Locate the spiracles on either side of the head, behind the eyes, but before the gills (Figure 3).
5. Place the gun's bolt along the midline and directly between the spiracles, ensuring the bolt end is flush with the head.
6. Gently squeeze the trigger to release the bolt.

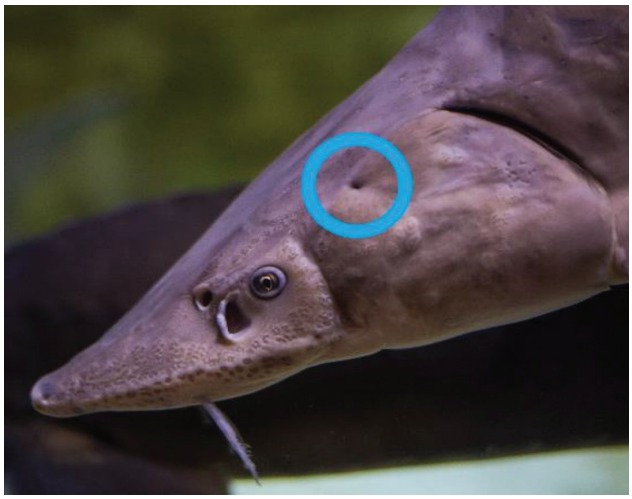

Photo: Natalia Kokhanova, Shutterstock

Figure 3. The spiracle (circled in blue) is a small opening located behind the eyes in sturgeon.

Sturgeon (*Acipenser* spp.) are the largest freshwater fish in North America. They have an average lifespan of 50–60 years, making them some of the longest-living fish on earth.

The effectiveness of percussion stunning can be compromised when the sturgeon's head is not laid flush against a solid, non-flexing surface, as elevation above a hard surface or submersion in water leads to the dispersion of the striking force. To reduce the possibility of restrikes and maximize force transfer, ensure the fish is positioned correctly and that the bolt end is flush against the head of the fish before pulling the NPCB trigger (Figure 4).

Suggestions for Improving the NPCB Application

Equipment Cleaning and Maintenance

Ensure NPCBs are cleaned and maintained according to the manufacturer's instructions before and after every use.

Proper maintenance and cleaning ensure the equipment operates effectively and reduces the risk of malfunction, thereby ensuring consistent performance, occupational health, and animal welfare.

Staff Training and Supervision

All staff members should be trained on the use, safety, and maintenance of the NPCB and working with high-pressure hoses and equipment.

Each staff member involved in the harvest process should receive training in the form of technical documents and physical demonstrations before equipment use. Supervision should be provided to ensure proper use and adherence to protocols. The supervisor is ultimately responsible to ensure this process is done efficiently and safely. Proper training and supervision ensure that staff are competent in operating the equipment safely and effectively, which is crucial for maintaining animal welfare standards.

Gas Supply

Maintain a reliable gas supply for pneumatic captive bolts to ensure high enough pressure for a single, effective strike with no chance of recovery.

Using compressed gas from a gas bottle managed by a regulator is preferable as it ensures consistent pressure for every strike (Figure 5). Compressors are acceptable if they can maintain the minimum required pressure during peak production periods. Consistent gas pressure is crucial for delivering humane and effective strikes, as pressure variations can lead to improper strikes and cause undue stress to the fish. Depending on the NPCB gun and the size of the fish, typical gas pressures for white sturgeon range from 145 to 250 PSI. The use of the adapter fitting allows for a convenient location to apply hydraulic tool oil lubricant and a quick connect and disconnect with the high-pressure airline.

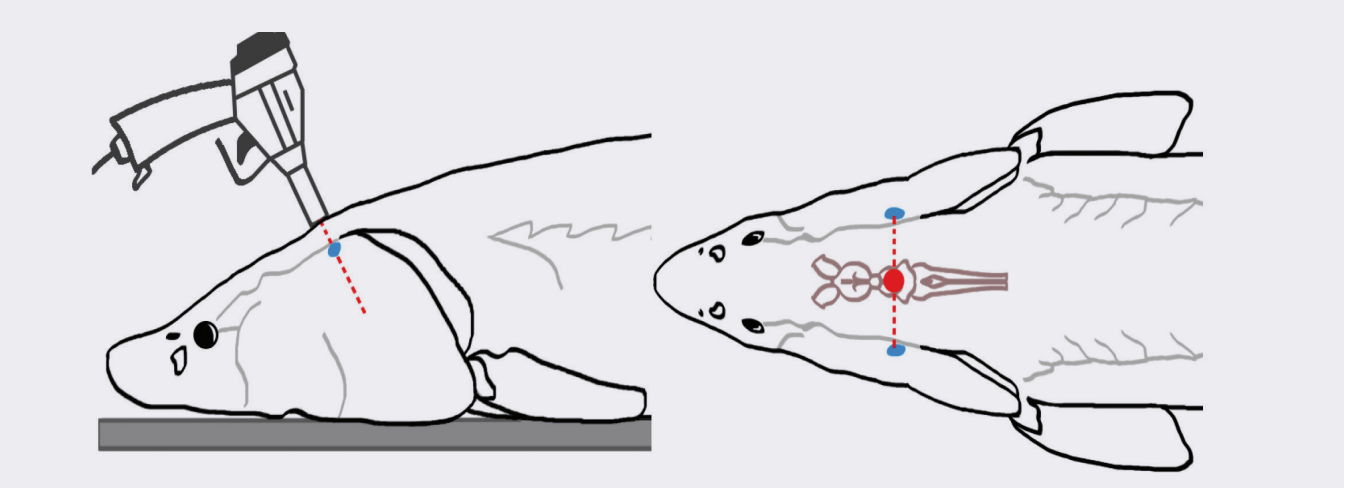

Illustration: Jennifer Bowman

Figure 4. Lateral (left) and dorsal (right) illustration of white sturgeon head with correct midline strike placement between lateral spiracles (blue) and brain anatomy.

Photo: Jackson Gross

Figure 5. Overhead view of the components used in this study: secured nitrogen tank with regulator, 20 ft of 1/4-inch, high pressure airline hose, locking cylinder cap, and NPCB gun.

Hoses and Fittings

Regularly inspect hoses and fittings for cracks or leaks and immediately replace any damaged or failing components.

Cracked hoses and leaking fittings are unsafe and can cause a decrease in operating pressure, leading to ineffective strikes. Ensuring all components are in good condition maintains the necessary pressure for a repeated humane and effective strike. We recommend removing the Schrader valve and replacing it with a 1/8th brass or stainless- steel pipe plug fitting at the rear of the Jarvis NPCB gun (Figure 5), as monitoring the output pressure is now achieved at the regulator. Furthermore, the valve has a high likelihood of leaking gas over time and can become damaged during operations.

Backup Equipment

Keep extra fittings, O-ring, and an additional NPCB on hand as backups.

In the event of equipment failure, readily available spare parts and a backup NPCB minimize downtime and ensure that operations can continue smoothly even if a component fails. This preparedness helps maintain consistent and humane treatment of the fish and minimal interruption to farm operations.

Proper Fish Positioning

It is crucial that the heads of fish are laid flush against a sturdy, non-flexible surface before NPCB strike to ensure adequate force transfer.

Laying the fish against a hard, non-flexible surface maximizes the force transfer from the bolt, ensuring the strike is effective and humane. This practice minimizes the risk of incomplete stunning, thereby reducing the need for multiple strikes or recovery during exsanguination.

Proper Bolt Positioning

Ensure the bolt is laid flush to the head of the sturgeon, taking time to position the strike point at the midline between lateral spiracles.

Proper positioning of the bolt is essential for an effective strike. The midline between the lateral spiracles is the optimal point for stunning a sturgeon. Deviations in placement towards the head, tail, or to either side of the midline will likely result in fish recovery. In this case, the best practice would be to immediately apply a second strike, ensuring a quick and humane process. Accurate placement minimizes the risk of recovery and ensures animal welfare.

Non-Penetrating Captive Bolt vs Penetrating Captive Bolt

Use non-penetrating captive bolts instead of penetrating bolts.

Due to the narrow width of the sturgeon brain and the likelihood of fish movement, it is more difficult to ensure a perfect strike with penetrating bolts, which can lead to repeated attempts and poor animal welfare. Non-penetrating bolts have a wider striking surface area and reduce the risk of multiple strikes, ensuring improved animal welfare.

Validating Insensibility

Validate insensibility after the strike to prevent recovery during exsanguination.

After the strike, immediately check for signs of insensibility by ensuring the fish's jaw is relaxed. Good animal welfare practices include touching gill rakers to assess a physical response to stimuli. If there is any movement of the gills, it suggests the fish was ineffectively stunned and requires an immediate

follow-up strike. This practice ensures that the fish does not recover and is treated humanely throughout the process.

Overall Project Background and Objectives

A recent study titled "Evaluation of non-penetrative captive bolt stunning as a method of slaughter for white sturgeon (*Acipenser transmontanus*)" assessed the efficacy of NPCB stunning as a humane slaughter method for white sturgeon.[7] Due to their size and cartilaginous anatomy, white sturgeon are of particular concern. The research examined the effectiveness of NPCB stunning in juvenile and adult sturgeon to highlight potential animal welfare and occupational safety within the aquaculture industry.

Major Objectives

The primary objectives of the study were to:

- Assess the efficacy of NPCB stunning as a humane slaughter method for juvenile meat fish and adult caviar-ready white sturgeon.
- Determine appropriate NPCB operating pressures for the most common sturgeon sizes.
- Evaluate recovery following the use of appropriate NPCB operating pressures.
- Validate the challenges of applying NPCB stunning to cartilaginous fish using histological examinations of brain tissue.

Determining NPCB Operating Pressures

Stunning study: A dose-dependent study was conducted on the two standard-size classes of white sturgeon: 2–3-year-old juvenile males and 6–9-year-old caviar-ready females. Conte (2010) previously established the placement of the strike,[8] and pilot studies determined the operating pressures tested. Each size class of fish had three different strike pressures tested.

Methodology: A Jarvis HPS-1 pneumatic NPCB (Bunzyl Processing Division, Riverside, MO) with a 2.5 cm diameter bolt was used to deliver a cranial concussion to white sturgeon at Sterling Caviar in Elverta, CA. Compressed nitrogen gas pressure was monitored and adjusted via a regulator (RADNOR Nitrogen Purge model GP 250-500-580). Consistency of strike placement was ensured by locating the two spiracles behind the eyes on either side of the head (Figure 6) and placing the bolt of the NPCB along the midline. The strike point is located directly above the hindbrain of the sturgeon and ensures maximum force is transferred to the brain. Pressures of 120, 135, and 145 PSI were used on juvenile male sturgeon

Photo: Jackson Gross

Figure 6. An NPCB gun is held flat against the head of an adult white sturgeon during the first step in the slaughter process.[7]

(n = 10, mean mass = 8.4 kg), and pressures of 175, 200, and 225 PSI were used on adult female sturgeon (n = 9, mean mass = 27.1 kg).

Following delivery of a single strike, jaw relaxation was assessed before exsanguination. Complete jaw relaxation (Figure 7) is an industry-accepted visual indicator of sturgeon insensibility. All fish were exsanguinated and placed in ice slurry as a second-step termination method.

Histological analysis: An hour after slaughter, a section of cartilage containing the brain of fish used in the stunning study was collected for analysis by the UC Davis Veterinary Pathology Laboratory. Brain tissue was analyzed for tissue damage consistent with acute traumatic brain injury (hemorrhage, cartilage necrosis, axonal and neuronal swelling, or edema). A grading system was used to quantify the severity of intracranial hemorrhage, ranging from 0 (feature absent) to 3 (severe hemorrhage).

Photo: Jackson Gross

Figure 7. Demonstration of jaw relaxation in an adult white sturgeon following a successful NPCB strike.[7]

Results: In both age classes, the highest PSI tested resulted in immediate jaw relaxation indicative of insensibility (145 PSI for juveniles; 225 PSI for adults). Histological analysis showed that NPCB significantly altered the integrity of brain tissue in juveniles but not in adult sturgeon (Figure 8).

Evaluating recovery following the use of appropriate NPCB operating pressures

Recovery study: A follow-up recovery study was carried out to confirm jaw relaxation as a visual indicator of sensibility in juvenile and adult white sturgeon using pressures established as effective during the previous study.

Methodology: The experiment was conducted during on-farm slaughter activities at Sterling Caviar. Juvenile and adult white sturgeon were struck using a Jarvis HPS-1 pneumatic NPCB with a 2.5 cm diameter bolt at pressures of 145 and 225 PSI,

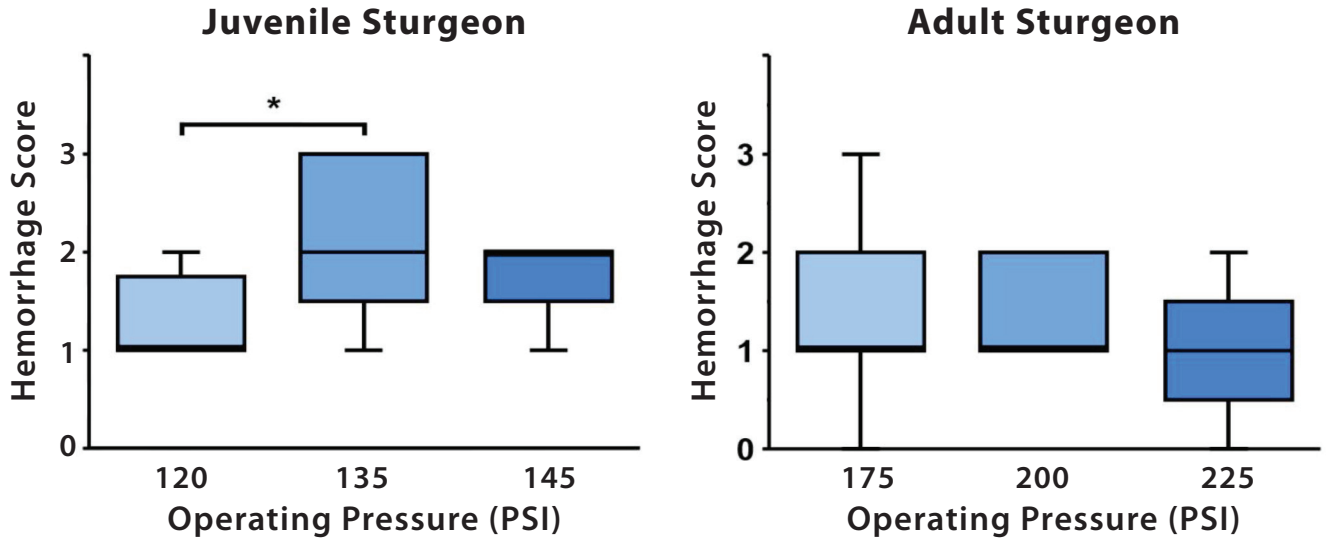

Figure 8. Categorical scores for regionally specific hemorrhage ratings for individual juvenile and adult white sturgeon brains exposed to a single strike using a non-penetrating captive bolt gun. "*" indicates a significant difference ($p < 0.05$) in hemorrhage between pressures.[7]

respectively. Over a single day, individual juvenile sturgeon (n = 100 total) were removed from a fish tote and placed on a stainless-steel table before being struck using a pressure of 145 PSI. Fish were exsanguinated in an ice slurry and monitored for signs of recovery. To avoid interfering with the harvest process after the monitoring period, only a portion of the juvenile sturgeon had mass and lengths recorded (n = 60, mean mass = 8.0 kg, mean length = 100.6 cm). Adult, 7.5-year-old female white sturgeon (n = 65, mean mass = 14.8 kg, mean length = 133 cm) were struck using 225 PSI immediately after removal from the fish tank and exsanguinated in an ice slurry. Adult fish were monitored in the ice slurry following the NPCB application (Figure 9). All sturgeon had gill rakers touched immediately after the strike to evoke a bodily response, and signs of opercular or muscle movement were monitored for two hours during the exsanguination period before processing.

Results: No juvenile sturgeon recovered following an NPCB stun at 145 PSI. When stunned using 225 PSI, 59 of the 65 adult sturgeons did not recover following a single NPCB strike. Six adult fish required an immediate second strike, while one fish required a third strike during the 2-hour exsanguination monitoring period.

Figure 9: Juvenile sturgeon being monitored for signs of recovery in tanks following NPCB application.[8]

Proper training and supervision ensure that staff are competent in operating the equipment safely and effectively, which is crucial for maintaining animal welfare standards.

For a slaughter process to be considered humane, insensibility must be achieved within one second of application and maintained throughout the entire process.[5]

Summary

For a slaughter process to be considered humane, insensibility must be achieved within 1 second of application and maintained throughout the entire process.[5] Results of the study suggest that using a Jarvis HPS-1 non-penetrative captive bolt can be an effective method for rendering juvenile and adult sturgeon insensible and that insensibility can be maintained until death. Histology results showed that the thick, cartilaginous skull protects from brain injury, but at least a degree of insensibility is inferred based on jaw relaxation, an industry-accepted indicator of unconsciousness for sturgeon.

A minimum operating pressure of 145 PSI is recommended for juvenile white sturgeons. Due to more than a 10% recovery rate in adult white sturgeon at the pressures tested during the recovery study, we recommend an operating pressure of 250 PSI to achieve effective percussion stunning with an NPCB applied over a sturdy, flat striking surface, followed by exsanguination. While these pressures are effective for juvenile and adult white sturgeon, there may be lower settings for younger classes of white sturgeon for other tasks on the farm, such as culling populations or euthanasia. Additional research should be done on the effectiveness of 250 PSI strikes on adult white sturgeon. Other NPCBs that are available on the market may lack the manufacturers' recommended operating pressures necessary to stun fish at the sizes tested in this study. These tools may be acceptable for younger or smaller sturgeon species, but additional research is needed to confirm their suitability.

Aquaculture is one of the fastest-growing protein industries in the world,[9] and the importance of practices that ensure good animal welfare should grow alongside it. The current lack of research into sturgeon welfare at the time of slaughter[3] means that developing an effective protocol is crucial and will increase the welfare of large finfish at harvest on a global scale. Establishing a more effective and humane slaughter protocol is essential to promote positive animal welfare and ensure that sturgeon are stunned effectively and do not recover before death. Safe and effective harvest practices will help safeguard the well-being of fish and staff during processing. The use of NPCB is a considerable improvement in animal welfare over currently used practices.

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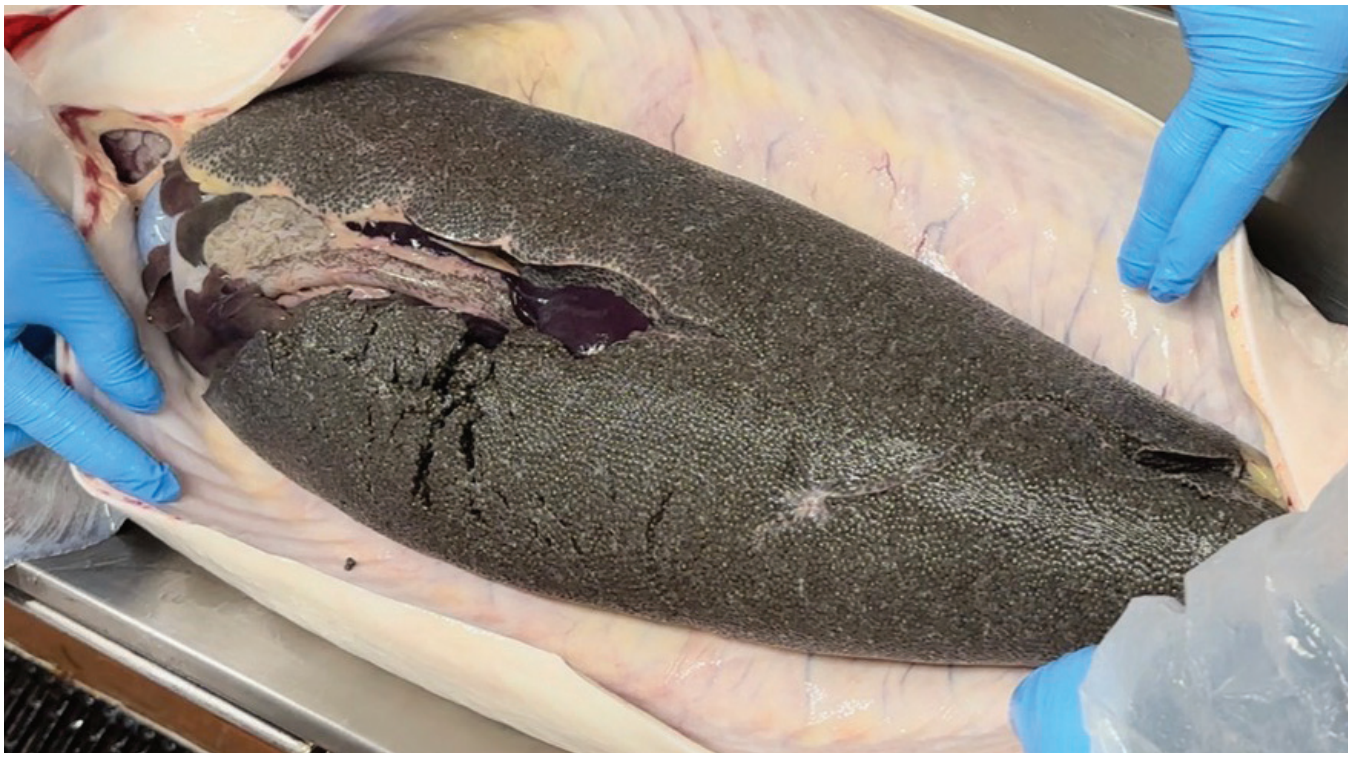

Photo: Courtesy of Jackson Gross

Processors gently pull back the skin of an adult female white sturgeon to show the ovaries, heavily laden with black fish eggs.

Additional Information

Article

Evaluation of non-penetrative captive bolt stunning as a method of slaughter for white sturgeon (*Acipenser transmontanus*)): https://doi.org/10.3389/fanim.2024.1405554

File

AVMA guidelines for the humane slaughter of animals, 2024 edition:
https://www.avma.org/sites/default/files/2024-09/Humane-Slaughter-Guidelines-2024.pdf

Videos

- Innovations in fish farming: how to kill a fish, captive bolt gun review:
  https://youtu.be/hy2U7QL0WQw?si=YU9o4RpcN9NF5McJ
- Is Fish Farming Factory Farming? Animal Welfare in Aquaculture:
  https://youtu.be/7qSiNjSicjA?si=lcckPV0ueFrOmC6I
- Best fish dissection: White sturgeon:
  https://youtu.be/FS9Z-6XWEHI?si=H2kf2J3LmMuhNNdz

Equipment

Jarvis HPS-1 Non-penetrating air-powered stunner:
https://bunzlprocessor.com/jarvis-hps-1-non-penetrating-pneumatic-stunner/

Acknowledgments

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