Subject: Request for External Review of Draft USGS Sturgeon Science Document

I hope this message finds you well. I am reaching out to request your assistance with the external review of the attached draft document titled *The State of Science in Sturgeon and Paddlefish Research in the U.S. Geological Survey: Past Activities and Future Directions*. This draft has been prepared by the USGS Sturgeon and Paddlefish Workgroup as part of the Species Management Research Program within the Ecosystems Mission Area.

This document aims to consolidate and synthesize decades of USGS research on sturgeon and paddlefish, while also outlining a strategic science vision for future research. Its purpose is to serve as a guiding resource for advancing sturgeon and paddlefish conservation efforts by identifying critical research gaps, supporting policy development, and enhancing collaboration across agencies, organizations, and stakeholders.

Please note that this is **not a final document** but rather a **first draft** that is intended to be further refined based on the external input we receive. As this is a draft, we kindly request that you do not cite or use the information contained within in the wrong context or manner, as the document will undergo significant revisions before finalization. Additionally, the appendices for this document are not yet complete but will be included in future versions.

This review is open to anyone who has an interest in helping advance a shared USGS vision for Sturgeon and Paddlefish science. Your feedback will be instrumental in helping us revise the document, make updates and corrections, and incorporate your input into a final version. Specifically, we are seeking insights on:

- Accuracy and completeness of the scientific content
- Relevance and application of the research findings to conservation efforts
- Suggestions for additional research needs or knowledge gaps
- Opportunities for enhancing collaboration and data sharing

We hope that you will see your own efforts and contributions to these species reflected in the document, and that it captures the collective work and dedication of everyone involved in sturgeon and paddlefish conservation.

How to Submit Your Input:

- Dave Hu, USGS Fish and Aquatic Species Program Manager, has been designated as the point of contact for all responses and any questions you may have. Please submit any feedback directly to Dave at dhu@usgs.gov by **COB January 15, 2025**.
- You can provide your feedback in any of the following ways:
    - Add comments and edits directly into the document and return using tracked changes.
    - Provide feedback in any other written form, such as a separate document or email.

Thank you in advance for your time and expertise. Your contributions will significantly strengthen the final version of this important document and ensure it reflects the collective knowledge of our research community.

Best regards,

Melanie Steinkamp
USGS Species Management Research Program Coordinator

Mobile: 703-261-3128

DRAFT DOCUMENT: THE STATE OF SCIENCE IN STURGEON AND PADDLEFISH RESEARCH IN THE U.S. GEOLOGICAL SURVEY - PAST ACTIVITIES AND FUTURE DIRECTIONS

ECOSYSTEMS MISSION AREA - SPECIES MANAGEMENT RESEARCH PROGRAM

COOPERATIVELY DEVELOPED BY THE USGS STURGEON AND PADDLEFISH WORKGROUP

Please submit all responses and inquiries on this document to: **Dave Hu, USGS Fish and Aquatic Species Program Manager, dhu@usgs.gov**

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EXECUTIVE SUMMARY

Sturgeons and paddlefish, ancient species dating back over 200 million years, are among the most imperiled groups of animals on Earth. With 85% of their species facing extinction, these unique fish are integral to the biodiversity of freshwater, estuarine, and coastal ecosystems across the northern hemisphere. The U.S. Geological Survey (USGS) has been at the forefront of sturgeon and paddlefish research, providing vital insights into their biology, ecology, and conservation.

Established by the Organic Act of 1879, the USGS operates under the Department of the Interior (DOI). Initially tasked with classifying public lands and assessing geological resources, the USGS has expanded its mission to include the ecological sciences in addition to mitigating natural disasters, managing crucial resources, and safeguarding the quality of life for society. Its expertise and data holdings in earth and biological sciences position the USGS as a leader in multidisciplinary investigations necessary for sturgeon conservation.

This document consolidates decades of USGS research, synthesizes science to date, and outlines a path forward for research through a USGS strategic science vision for sturgeon and paddlefish research, categorized into the following themes. 1) *Life History and Ecology*, including research on reproductive biology, habitat use, and population dynamics, leveraging advanced technologies such as telemetry, sonar, and genetic analysis; 2) *Threats and Stressors*, including research on key threats such as overfishing, habitat loss, pollution, and climate change on sturgeon and paddlefish populations; and 3) *Population Research, Monitoring, and Management Efforts*, such as decision-support tools to inform policy and management decisions, and developing effective conservation strategies.

The USGS fosters inclusive collaborations with federal and state agencies, tribal organizations, universities, industry stakeholders, non-governmental organizations, and the public. These partnerships enhance research efforts and facilitate the integration of findings into policy, management, and citizen decisions.

This document emphasizes the need for enhanced collaborative efforts and data sharing. Addressing knowledge gaps and advancing research on sturgeon and paddlefish are crucial for

developing effective conservation and management strategies. By fostering collaboration and leveraging scientific expertise, the USGS is committed to ensuring the long-term sustainability of these ancient and iconic species for future generations. USGS research plays a pivotal role in protecting and managing at-risk species, ensuring the sustainability of healthy fish communities and populations. The collaborative efforts outlined in this document underscore the urgency and imperative for collective action to protect sturgeon and paddlefish, contributing significantly to the conservation, sustainability, and restoration of these invaluable aquatic species.

SECTION 1: INTRODUCTION

Sturgeons and paddlefish are ancient species that have roamed the earth for over 200 million years, predating dinosaurs. These unique fish are integral to the biodiversity of freshwater, estuarine, and coastal ecosystems across the northern hemisphere. However, they are among the most threatened groups of animals, with 85% of their species facing extinction due to a combination of overfishing, habitat loss, and water quality degradation (IUCN, 2010; Reinartz & Slavcheva, 2016)

This document is broken into three primary sections: 1) an overview of North American sturgeon and paddlefish species, detailing their distribution, life history, and conservation status; 2) a USGS science vision, outlining current and future key research under themes such as life history, ecology, threats, and management strategies; and 3) a call for action related to data and information needs, identifying critical research gaps and emphasizing the importance of collaboration and data sharing to advance conservation efforts. Together, these sections provide a comprehensive framework for guiding future research and policy development in sturgeon and paddlefish conservation.

DOCUMENT PURPOSE AND INTENDED USE

The primary objectives of this document are to:

- Consolidate and synthesize current USGS scientific knowledge on sturgeon and paddlefish species.
- Outline a strategic vision for advancing research within USGS, focusing on addressing key knowledge gaps and establishing research priorities.

- Serve as a comprehensive resource for the organizing and managing sturgeon and paddlefish initiatives within the USGS.
- Facilitate collaboration and partnerships among the USGS, other natural resource agencies, academic institutions, non-governmental organizations, tribal organizations, the public and other relevant stakeholders to support conservation efforts.

DOCUMENT ORGANIZATION

The document is structured into several sections to provide a comprehensive understanding of sturgeon and paddlefish research and conservation. Together, these sections provide a comprehensive framework for guiding future research and policy development in sturgeon and paddlefish conservation:

1. *Overview of North American Acipenseriformes.* This section details the various species of sturgeon and paddlefish, including their distribution and range, conservations status, life histories, status and threats, and outlining future research needs.
2. *USGS Strategic Science Vision.* This section outlines the USGS's strategic research under three general research categories, with a set of detailed focal research areas identified under each.
    - *Research Category 1: Life History and Ecology* focuses on exploring the reproductive biology, habitat use, genomic diversity, migratory behaviors, and culture techniques of sturgeon and paddlefish to support their conservation and population recovery. It is comprised of the following research focal areas:
        - *Focal Area 1A: Early and Late Life Histories, Physiology, and Reproduction* explores the reproductive biology, physiology, and early and late life histories of sturgeon and paddlefish.
        - *Focal Area 1B: Distributions, Habitat Use, and Habitat Suitability* investigates the distribution, habitat use, and suitability of environments across various life stages.
        - *Focal Area 1C: Genomic Analyses and Population Viabilities* focuses on genomic analyses used to assess population viabilities, genetic diversity, and hybridization threats.

123 - *Focal Area 1D: Passage Behavior and Migrations* focuses on the
124 migratory behaviors and passage challenges faced by sturgeon and
125 paddlefish, particularly in rivers affected by dams and other barriers.
126 - *Focal Area 1E: Culture and Propagation* focuses on developing and
127 optimizing culture and propagation techniques to support population
128 recovery and ensure genetic diversity in declining populations.
129 - *Research Category 2: Threats and Stressors* focuses on understanding and
130 mitigating the impacts of commercial harvesting, pollutants, diseases, invasive
131 species, habitat degradation, and water flow changes on sturgeon and paddlefish
132 populations, with the goal of developing sustainable conservation strategies. It is
133 comprised of the following research focal areas:
134 - *Focal Area 2A: Commercial and Recreational Harvest, Caviar Industry,*
135 *and Mortality Impacts* focuses on the impacts of commercial and
136 recreational harvesting, particularly for caviar, on sturgeon and paddlefish
137 populations, and developing strategies for sustainable fishery practices.
138 - *Focal Area 2B: Effects of Pollutants and Contaminants* focuses on the
139 effects of pollutants, including endocrine-disrupting chemicals and heavy
140 metals, on the health and reproduction of sturgeon and paddlefish.
141 - *Focal Area 2C: Diseases and Pathogens* investigates the diseases and
142 pathogens affecting sturgeon and paddlefish, with a particular emphasis on
143 viral, bacterial, and parasitic infections.
144 - *Focal Area 2D: Influence and Impacts of Invasive Species and Control*
145 *Measures* addresses the competitive pressures and habitat disruptions
146 caused by invasive species, as well as the effectiveness of control
147 measures for protecting native populations.
148 - *Focal Area 2E: Habitat Degradation/Dredging Impacts* examines the
149 effects of habitat degradation and dredging activities on sturgeon and
150 paddlefish.
151 - *Focal Area 2F: Water Flows, Quality, and Availability Impacts.* Research
152 investigating how changes in water flow, quality, and availability impact

sturgeon habitats, migration, and reproductive success, particularly under changing climate conditions.

- *Research Category 3: Population Research, Monitoring, and Management Efforts* focuses on developing adaptive management tools, monitoring population trends, and securing funding and resources to support ongoing research and conservation efforts for sturgeon and paddlefish populations. It is comprised of the following research focal areas:
  - *Focal Area 3A: Sensitive Species Adaptive Management, Decision Support, and Recovery Planning*. Research for developing adaptive management and decision-support tools to guide conservation strategies and ensure the recovery of sensitive sturgeon and paddlefish populations.
  - *Focal Area 3B: Sensitive Species Monitoring.* Research for monitoring and tracking population trends, habitat use, and the health of sturgeon and paddlefish populations.
  - *Focal Area 3C: Research Funding and Resources*. This emphasis area focuses on the importance of securing funding and resources, as well as fostering collaboration to support ongoing research and conservation initiatives for sturgeon and paddlefish.

3. *Data and Information Needs.* This section focuses on the development of a national data and research network and identifies critical areas requiring further research and investigation.

ON THE NEED FOR STURGEON AND PADDLEFISH RESEARCH

Sturgeons and paddlefish, ancient species that have existed for over 200 million years, are facing unprecedented threats that have brought them to the brink of extinction. Research into their conservation and management is critically important due to the multifaceted challenges they face. Most species of sturgeon and paddlefish are threatened with extinction, primarily due to overfishing and habitat degradation and compounded by their slow reproductive rates and specific habitat requirements. White and lake sturgeon, while facing conservation challenges, are relatively secure.

THREATS AND CHALLENGES

Overfishing. Sturgeon populations have been historically overexploited for their valuable roe, flesh, and other products. The high demand for caviar has led to unsustainable fishing practices that have decimated populations. Despite regulations, illegal fishing and bycatch continue to pose significant threats to sturgeon and paddlefish. Many populations have not recovered from past overfishing, and ongoing pressures exacerbate their decline.

Habitat Loss and Degradation. The proliferation of dams across waterways has severely impacted sturgeon and paddlefish by blocking access to critical spawning habitats, altering natural water flow patterns, and changing temperature regimes essential for reproductive success. For instance, the construction of the Holyoke Dam on the Connecticut River and the Edwards Dam on the Kennebec River has had significant impacts on local sturgeon populations.

Industrial and Municipal Development. Urbanization and industrial activities along river systems have led to habitat encroachment and pollution. These activities degrade the water quality and reduce the availability of suitable habitats for sturgeon and paddlefish.

Sedimentation and Dredging. Navigation and flood control projects often involve dredging, which destroys spawning grounds and nursery habitats. Sedimentation from agricultural runoff and deforestation further degrades the water quality and in-water habitats of rivers.

Pollution, Contaminants, and Diseases. Contaminants from industrial sources, including heavy metals and persistent organic pollutants, accumulate in the tissues of sturgeons and paddlefish, leading to health problems and reduced reproductive success. Nutrient runoff from agricultural lands leads to eutrophication, which can cause harmful algal blooms and deplete oxygen levels in water bodies, affecting sturgeon and paddlefish habitats. Discharges of untreated or partially treated sewage introduce pathogens and pollutants into rivers, further degrading water quality and impacting fish health.

Invasive Species. Invasive species, such as invasive carps, compete with sturgeon and paddlefish for food and habitat, while other invasive species may prey on their eggs and juveniles. Invasive species can alter the structure and function of aquatic ecosystems, making them less hospitable for native sturgeon and paddlefish.

Climate Change. Rising temperatures can alter the timing of spawning and the availability of suitable habitats, affecting the reproductive success of sturgeon and paddlefish. Climate change can lead to altered precipitation patterns and increased frequency of extreme weather events such

as droughts and floods impacting river flow regimes and habitat availability for all life stages of sturgeons and paddlefish. Warming temperatures may contribute to physiological stress and observed summertime mortality events for sturgeon species.

USGS ROLES AND CAPACITIES IN STURGEON AND PADDLEFISH RESEARCH

Established by the Organic Act of March 3, 1879, the U.S. Geological Survey (USGS) operates under the Department of the Interior (DOI). Initially tasked with classifying public lands, examining geological structures, assessing mineral resources, and understanding the nation's geological processes, the USGS has since expanded its mission. Today, it provides vital scientific insights into Earth's physical, biological, and chemical dynamics, encompassing mitigation of natural disasters, management of crucial resources like water, energy, and minerals, and safeguarding the overall quality of life for society. The USGS is the primary research science agency within the DOI, employing over 8,000 individuals, including scientists, technicians, and support staff, stationed across 400 locations nationwide. Its expertise and vast data holdings in earth and biological sciences make it a sought-after partner by numerous entities spanning governmental, academic, and private sectors.

Significant strides have been made in sturgeon research by the USGS in recent decades. However, persistent knowledge gaps hinder current conservation and management initiatives. The dynamic nature of freshwater habitats, influenced by climatic shifts and landscape alterations, presents ongoing challenges. Uncertainties persist regarding the impact of these changes on river flows and associated habitats and how these factors affect the movement and reproductive behaviors of large-bodied fishes, including sturgeon and paddlefish.

The USGS stands at the forefront of sturgeon research, uniquely positioned to undertake comprehensive multidisciplinary investigations necessary for sturgeon conservation. The agency leverages its extensive expertise internally across various USGS mission areas and externally through collaborative efforts with research partners. The USGS's research capabilities are enhanced by its use of state-of-the-art technologies enabling comprehensive studies that gather vital data essential for developing effective conservation strategies.

USGS CONTRIBUTIONS TO STURGEON AND PADDLEFISH SCIENCE AND CONSERVATION

- *Comprehensive Studies*. USGS scientists conduct in-depth research on sturgeon and paddlefish populations, focusing on their habitats and ecological interactions. This includes investigations into reproductive biology, habitat use, population dynamics, and genetic diversity to better understand the factors driving species sustainability.
- *Advanced Technologies.* USGS researchers are at the forefront of developing and applying advanced technologies, such as telemetry, sonar, and molecular and genetic analyses. These innovations allow the collection of crucial data on the movement, behavior, and health of sturgeon and paddlefish, offering valuable insights into habitat preferences, migration patterns, and population structures.
- *Extensive Data Holdings.* The USGS maintains vast repositories of data in both earth and biological sciences. This wealth of information supports long-term monitoring efforts and enables researchers to identify trends, assess ecosystem health, and detect emerging threats to sturgeon and paddlefish populations.
- *Interdisciplinary Expertise.* USGS scientists integrate expertise from various disciplines—including biology, ecology, hydrology, toxicology, pathology, genetics, taxonomy, physiology, immunology, and the social sciences, ensuring a comprehensive understanding of the complex challenges facing sturgeon and paddlefish conservation.
- *Scientific Insights and Recommendations*. The USGS provides scientific insights and recommendations to inform policy and management decisions. This includes advising state and federal management agencies on activities that may impact sturgeon and paddlefish resources, guiding efforts to minimize potential threats.
- *Decision-Support Tools.* USGS scientists develop decision-support tools designed to inform conservation strategies and predict future scenarios. These tools integrate the latest research findings, helping policymakers and resource managers make informed, data-driven decisions to support the conservation and sustainable management of sturgeon and paddlefish populations.
- *National and International Partnerships.* The USGS fosters collaborations with a wide range of partners, including federal, state, and provincial agencies, Tribal Nations, academic institutions, industry stakeholders, and non-governmental organizations. These

partnerships enhance research initiatives and ensure that scientific findings are effectively integrated into policy and conservation practices.

- *Global Conservation Efforts*. The USGS plays a key role in global sturgeon conservation by working across interjurisdictional boundaries. Through international collaborations, the USGS shares expertise, data, and resources to address global challenges in sturgeon conservation, ensuring the preservation of these species for future generations. Notable examples include partnerships in Georgia, focusing on sonar and genetics research for ESA and CITES-listed Eurasian taxa, and in Canada, where the USGS contributes to genetic studies of Atlantic Sturgeon.

CASE EXAMPLE

Gulf of Maine Sturgeon Research Collaboration. This long-term initiative involves researchers from the USGS, University of Maine, New England University, the Maine Department of Marine Resources, and the United States Navy. It focuses on documenting inter-basin movements, spawning success, and critical habitats of sturgeon. Support comes from various stakeholders, including state and federal conservation agencies, non-profit organizations, local authorities, and the ACT/MATOS acoustic tag network.

USGS SCIENCE CENTERS

The USGS's extensive expertise, advanced laboratory facilities, and collaborative approach position it uniquely to address the complex challenges facing sturgeon and paddlefish conservation. USGS Science Centers encompass various science specializations aimed at advancing scientific knowledge and understanding.

- *USGS Ecological Science Centers.* These centers study the intricate dynamics of ecosystems, including biodiversity, ecological processes, and interactions between organisms and their environments. Research generated informs policy decisions and land management practices, contributing to the conservation and sustainable management of natural resources.
- *USGS Cooperative Fish and Wildlife Research Units***.** Established in 1935 and integrated into the USGS in the mid-1990s, there are 43 units distributed across 41 states. Each unit represents a collaboration among the USGS, a designated host university, one or more

state agencies, and the Wildlife Management Institute. These units serve as pivotal hubs for collaborative research endeavors, fostering partnerships between natural resource agencies.

- *USGS Water Science Centers.* These centers play a crucial role in understanding and managing water resources. They conduct research, monitor water quality, assess hydrological trends, and provide vital data for informed decision-making regarding water usage, conservation, and environmental protection.
- *USGS Climate Adaptation Science Centers.* Focused on researching and developing strategies to mitigate and adapt to the impacts of climate change, these centers conduct interdisciplinary studies to understand climate dynamics, predict future trends, and devise adaptive measures to safeguard ecosystems, wildlife, and human communities.

USGS NATIONAL PROGRAM AREAS

Ecosystems Mission Area

The USGS Ecosystems Mission Area provides scientific information critical for understanding the health, status, and trends of the nation's ecosystems and the biodiversity they support. This area integrates biological research with ecosystem management to ensure the sustainable use of natural resources. Key components related to sturgeon and paddlefish include:

- *Species Management Research Program.* Focuses on the conservation and restoration of sturgeon and paddlefish species and populations, ensuring their long-term survival and genetic diversity. This program supports research that informs conservation strategies across a range of species.
- *Biological Threats and Invasive Species Research Program.* Conducts research on invasive species and pathogens that pose significant risks to sturgeon and paddlefish.
- *Environmental Health Research Program.* Evaluates the impact of contaminants and pathogens on sturgeon and paddlefish, ensuring that water quality and ecosystem health are conducive to the sustainability of these species.
- *Land Management Research Program.* Conducts research related to land use and conservation, ensuring that critical habitats for sturgeon and paddlefish remain intact amidst land use and development pressures and changes.

- *Cooperative Research Units.* A network of partnerships between USGS, universities, and state agencies, focusing on state agencies research needs for fisheries.
- *Climate Adaptation Science Centers.* Assess how ecosystems, including fisheries, adapt to climate variability and change. These centers conduct research to understand the impacts of climate change on aquatic species like sturgeon and paddlefish, including their habitat needs, migration patterns, and population health.

Water Resources Mission Area

The USGS Water Resources Mission Area provides comprehensive data on the nation's water resources, informing water management, policy decisions, and public safety. Research focuses on water quantity, quality, distribution, and availability, which are essential for the habitats of sturgeon and paddlefish.

- *Groundwater and Streamflow Information Program.* Delivers real-time data on water levels and streamflow, crucial for maintaining healthy ecosystems that support sturgeon and paddlefish.
- *National Water Quality Program.* Monitors water quality across the nation, including key habitats for sturgeon and paddlefish. This program helps identify pollution sources and provides data to help mitigate the impact of contaminants on these sensitive species.
- *Water Availability and Use Science Program*. Evaluates the availability of water for sturgeon and paddlefish habitats, helping to evaluate if sufficient water flows exist to support critical ecological processes, such as spawning and foraging.
- *Water Resources Research Act Program.* Supports critical research that addresses water-related challenges impacting sturgeon and paddlefish habitats. This program funds projects that focus on understanding and improving water availability, quality, and management, which are essential for maintaining healthy aquatic ecosystems.

Core Science Systems Mission Area

The Core Science Systems Mission Area provides foundational data and scientific tools essential for supporting a wide range of research and decision-making processes. Its programs are critical for mapping, monitoring, and understanding the physical, biological, and geographical aspects of ecosystems, including those affecting sturgeon and paddlefish conservation.

- *Science Analytics and Synthesis Program.* Provides comprehensive data integration, advanced analytical tools, and robust data management practices, enabling researchers to synthesize vast amounts of ecological data and make informed decisions for the conservation and management of these vital species.
- *National Geospatial Program.* Provides advanced data integration and analytical tools that allow researchers to synthesize large datasets, including ecological data on sturgeon and paddlefish.

SECTION 2: OVERVIEW OF NORTH AMERICAN ACIPENSERIFORMES

INTRODUCTION TO NORTH AMERICAN STURGEON AND PADDLEFISH

Sturgeons and paddlefish belong to an ancient lineage of fishes known as Acipenseriformes, which dates back to the Lower Jurassic period, over 200 million years ago. These species have survived multiple global extinction events, retaining many of their primitive features. Acipenseriformes are divided into two families. Acipenseridae (sturgeons) and Polyodontidae (paddlefish). Sturgeons are characterized by their elongated bodies covered with bony scutes, long snouts, and sensory barbels. They possess a largely cartilaginous skeleton with a bony skull and pectoral girdle. Paddlefish, on the other hand, lack scales and scutes, and are distinguished by their elongated, paddle-like rostrum. They have a similar cartilaginous skeleton structure, with bone only in the jaw. This ancient lineage is known for its evolutionary stability, having changed little over millions of years. Sturgeons and paddlefish exhibit unique and diverse life histories that have adapted to their respective habitats over millennia. These species are primarily found in temperate regions of the northern hemisphere, inhabiting freshwater, estuarine, and coastal environments. Their life histories are typically characterized by long lifespans, late sexual maturity, and intermittent spawning.

Sturgeon Life Histories. Sturgeons are known for their complex reproductive behaviors. Most species are anadromous, meaning they migrate from the sea into freshwater rivers to spawn. Spawning typically occurs in the spring, with females releasing thousands of eggs over gravel or

rocky substrates while males release sperm to fertilize them. Sturgeon larvae drift downstream to calmer waters where they grow and develop. They exhibit slow growth rates and can live for several decades, with some species, such as lake sturgeon, known to live over a century. As benthic feeders, sturgeons consume a variety of invertebrates and small fish, using their barbels to detect prey in the substrate. Their unique physiology allows them to tolerate low oxygen levels and be able to survive when exposed to challenging aquatic environments.

Paddlefish Life Histories. Paddlefish are also known for their distinctive reproductive behaviors. They are primarily found in large river systems with strong currents. Spawning occurs in the spring, often triggered by rising water levels, with females releasing eggs that adhere to submerged vegetation and other structures. Paddlefish grow rapidly compared to sturgeons and have a relatively shorter lifespan, typically ranging from 20 to 30 years. Research suggests that northern populations of Paddlefish exhibit significantly longer life spans compared to their southern counterparts. Scarnecchia et al. (2011) documented life spans of 40-50 years in the Yellowstone-Sakakawea Paddlefish stocks, with females reaching prime reproductive ages between 25 and 40 years. They transition from particulate feeding as juveniles to ram-filter feeding as adults, relying on gill rakers to filter plankton from the water. Paddlefish are filter feeders, primarily consuming zooplankton and small invertebrates. Their elongated rostrum is equipped with electroreceptors that help detect prey items in murky waters.

Together, sturgeons and paddlefish play vital ecological roles in their respective ecosystems. As large-bodied, long-lived species, they contribute to nutrient cycling and energy flow within aquatic environments. Their presence influences the structure and function of aquatic communities, and they serve as indicators of ecosystem health. Despite their ecological significance, sturgeons and paddlefish face numerous threats that have led to drastic declines in their populations. Habitat degradation, overfishing, pollution, and climate change are some of the major factors contributing to their precarious status. Sturgeons are threatened by overfishing, particularly for their roe, which is highly valued as caviar. Habitat loss due to dam construction, water pollution, and climate change further exacerbates their decline. Efforts to conserve sturgeon populations include habitat restoration, implementation of fishing regulations, captive breeding programs, and the construction of fish passage facilities at dams. Paddlefish face threats from habitat fragmentation caused by dams, pollution, and competition with non-native species like invasive carps. Overfishing for their roe and flesh also poses significant challenges.

Conservation measures for paddlefish include habitat protection, pollution control, regulation of fishing practices, and reintroduction programs in areas where populations have declined.

Alabama Sturgeon (*Scaphirhyncus suttkusi*)

Distribution and Range. The range of the Alabama sturgeon (*Scaphirhynchus suttkusi*) is limited to the Mobile Basin in Alabama and Mississippi. Historically, its range included the Coosa, Cahaba, Alabama, Black Warrior, Mobile, Tensaw, Tallapoosa, and Tombigbee rivers (Williams & Clemmer, 1991; USFWS, 1994). Since about 1985, confirmed records of the Alabama sturgeon have primarily been from the free-flowing portion of the Alabama River below the Claiborne (Millers Ferry) Lock and Dam, downstream to the mouth of the Tombigbee River in Clarke, Monroe, and Wilcox counties. A notable exception is a collection made in 1996 from approximately 60 miles above Claiborne (USFWS, 1994; Mayden & Kuhajda, 1996).

Conservation Status. Conservation efforts for the Alabama sturgeon are focused on several key areas to increase its population and preserve its genetic diversity. Ongoing initiatives include a captive breeding program, which, despite ongoing efforts, has yet to achieve success. The goal of this program is to propagate individuals for eventual release into the wild to bolster the natural population. Habitat protection is another crucial aspect, involving the mitigation of dam operations' impacts, pollution control, and the restoration of degraded habitats. Additionally, efforts are underway to conserve the genetic diversity of the Alabama sturgeon population, which is critical for the species' long-term viability.

Unique Life Histories. The Alabama sturgeon is a species of significant evolutionary interest due to its limited distribution and specialized habitat requirements. Historically, this species occupied a variety of riverine environments but is now largely restricted to a small segment of its former range. Its life history characteristics include delayed sexual maturity and spawning intervals that likely contribute to its vulnerability. Sturgeons, including the Alabama sturgeon, typically have long lifespans and intermittent spawning patterns, which are adapted to variable environments but are less suited to the heavily fragmented and hydrologically altered conditions of modern river systems.

Status and Threats. The Alabama sturgeon is one of the rarest fish species in the United States, and its population status is critically endangered. Efforts by state and federal fishery biologists from the spring of 1997 through the spring of 2001 resulted in the capture of only four

Alabama sturgeon, further substantiating the species' rarity (Parauka, 2004). The species was listed as endangered in 2000 due to its apparent inability to sustain a viable population (Parauka, 2004). The primary threats to the Alabama sturgeon include habitat fragmentation and degradation, overfishing, and competition with invasive species. Currently, there is a lack of physical captures in recent years and there are no known monitoring efforts identified specifically targeting the Alabama sturgeon.

Future Research Needs. Research is ongoing to develop a comprehensive understanding of the life history and habitat needs of the Alabama sturgeon. This information is vital for informing conservation strategies and implementing adaptive management practices. Conservationists are focusing on gathering data to tailor adaptive management strategies specifically to the needs of the Alabama sturgeon and its habitat, ensuring the species' survival and recovery.

American Paddlefish (*Polyodon spathula*)

Distribution and Range. The American paddlefish (*Polyodon spathula*) is found in the freshwater systems of North America, primarily within the Mississippi River basin. Its distribution extends from southwestern New York to central Montana and south to Louisiana (Grady, 2004). Additionally, the species inhabits the Gulf Slope drainages from the Mobile Basin in Alabama, primarily below the Fall Line (Mettee et al., 1996), to Galveston Bay in Texas (Page & Burr, 1991). Historically, the American paddlefish had a broader range, including occurrences in Canada, specifically in Lake Huron and Lake Helen, and across 26 to 27 states in the United States (Parker, 1988; Graham, 1997). However, the species is now believed to be extirpated in Canada, with no records since the early 1900s (Parker, 1988).

Conservation Status. The 1992 U.S. Fish and Wildlife Service status review concluded that listing the American paddlefish as threatened under the Endangered Species Act was not warranted. However, the species is currently listed as vulnerable on the International Union for Conservation of Nature (IUCN) Red List due to a perceived overall population size reduction of at least 30% within the next 10 years or three generations. This potential decline is attributed to exploitation, introduced taxa, pollutants, competitors, or parasites (Grady, 2004).

Unique Life Histories. American paddlefish are filter feeders, primarily consuming zooplankton. They are distinguished by their unique paddle-shaped rostrum, which aids in detecting planktonic prey in murky waters through electroreception. Paddlefish have a long

lifespan, often exceeding 30 years, and exhibit slow growth rates. They spawn in the spring, with rising water levels typically triggering the spawning process. Eggs are deposited over submerged vegetation or structures with flow, where they adhere until hatching.

Status and Threats. Despite being widespread, the American paddlefish faces several significant threats. The demand for caviar has led to both legal and illegal harvests, which have adversely impacted paddlefish populations. Additionally, increasing populations of exotic invasive carp species compete with paddlefish for food and habitat (Grady, 2004). Although competition, predation, and disease were not considered limiting factors in the 1992 review (USFWS, 1992), habitat and water quality concerns remain significant threats in several locations, particularly due to the presence of dams and pollution. While these challenges persist, many habitats previously occupied by paddlefish remain viable. The enforcement of U.S. laws, such as the Clean Water Act and the Fish and Wildlife Coordination Act, along with ongoing and future habitat improvement efforts aimed at benefiting pallid sturgeon breeding and nursery habitats, should also benefit the paddlefish.

Future Research Needs. Research on American paddlefish has identified several key areas that require further exploration to ensure effective conservation and management. Understanding the drift distance of larvae and the factors affecting recruitment, particularly in reservoirs, is crucial for managing paddlefish populations. Additionally, the use of side-scan, down-scan, and live-imaging sonar in monitoring paddlefish populations is an area of active research. Further study is needed to assess the impact of sonar technology on the species' vulnerability to exploitation, as this could have significant implications for their conservation.

CASE EXAMPLE

Sonar Estimation of Paddlefish. This research engages partners from several institutions and agencies including USGS Cooperative Research Unit at Oklahoma State University, USGS Columbia Environmental Research Center, and Oklahoma Department of Wildlife Conservation. Utilizing wild and stocked populations of American paddlefish in Oklahoma and Missouri, this research aims to refine estimates of American paddlefish using down-scan and side-scan sonar. With semi-autonomous kayaks, which can be programmed to follow the same sampling transects a fixed distance apart, estimates of detection can be made, which will allow for more precise estimates of abundance.

Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*)

Distribution and Range. Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) is the second largest sturgeon species in North America. This anadromous species inhabits the Atlantic coastal waters of Canada and the United States, with suitable spawning rivers in both countries. Historically, Atlantic sturgeon ranged along the Canadian and U.S. Atlantic Coast from Labrador to Florida. Although significantly reduced from historic levels, breeding populations still exist in at least 14 Atlantic Coast rivers in the U.S. (from Maine to Georgia) and several more in Canada, including the St. Lawrence and St. John rivers (St. Pierre, 1999). Efforts are ongoing to document additional spawning populations in other rivers. A 40-year harvest moratorium for Atlantic sturgeon was enacted in 1998 with the goal of protecting 20 year-classes of females in each spawning stock (NMFS, 1998a). Despite the moratorium in the U.S., a fishery for Atlantic sturgeon still exists in Canada, where exports, mostly to the U.S., are ongoing (Smith & Clugston, 1997; Williamson, 2003). Atlantic sturgeon was one of the first sturgeon species to be cultured in North America, with experimental restocking efforts conducted in the Hudson River and a tributary of the Chesapeake Bay (NMFS, 1998a; St. Pierre, 1999; Peterson et al., 2000; Secor et al., 2000).

Conservation Status. All U.S. populations of Atlantic sturgeon are currently listed under the Endangered Species Act. These populations are divided into five distinct population segments (DPSs): Gulf of Maine DPS (listed as threatened), New York Bight DPS (listed as endangered), Chesapeake Bay DPS (listed as endangered), Carolina DPS (listed as endangered), and South Atlantic DPS (listed as endangered). A thorough understanding of the abundance and distribution of Atlantic sturgeon remains lacking (NMFS, 1998a) and has been identified by the Atlantic States Marine Fisheries Commission as a high-priority research need. Recent efforts by researchers like Wippelhauser et al., (2017) have identified potential critical habitats, seasonal distributions, and detailed movements of Gulf of Maine Atlantic sturgeon, including the use of reconnected river habitats following dam removal.

Unique Life Histories. Atlantic sturgeon exhibit philopatric behavior, meaning they tend to return to their natal rivers to spawn. This behavior results in genetically distinct spawning populations with minimal intermixing between populations. Notably, at least three rivers host separate, genetically distinct spring and fall spawning runs. The species' reliance on specific habitats for different life stages underscores the importance of preserving their spawning grounds and migratory routes.

Status and Threats. Research on Atlantic sturgeon has concentrated on various aspects, including population dynamics, migration patterns, habitat requirements, physiology, and conservation strategies. Telemetry and genetic studies have provided insights into the migratory behaviors and population structures of Atlantic sturgeon, helping to delineate the movements of different DPSs and inform conservation strategies aimed at protecting critical habitats and migratory corridors. Research has also identified key spawning and feeding habitats essential for the survival of Atlantic sturgeon, highlighting the importance of effective habitat restoration and protection efforts. Studies on the physiological adaptations of Atlantic sturgeon, such as their tolerance to seawater and energy regulation, have informed conservation strategies. Recent research by McCormick et al. (2020) and Shaughnessy et al. (2023) has clarified the hormonal control of seawater tolerance and energy regulation mechanisms in Atlantic sturgeon.

Future Research Needs. Despite significant advancements in understanding Atlantic sturgeon, substantial knowledge gaps remain. Improved methodologies are needed to accurately assess the abundance and distribution of Atlantic sturgeon populations, which can enhance population monitoring, track the effectiveness of conservation measures, and identify emerging threats. Additionally, further research is required to evaluate the effectiveness of current conservation measures and to develop new strategies to mitigate threats such as habitat degradation, pollution, and climate change. The potential impact of climate change on estuarine salinity and saltwater intrusion into riverine systems utilized by Atlantic sturgeon necessitates a deeper understanding of essential physiological functions. Advancing research on the species' physiological responses to changing environmental conditions is critical for developing adaptive management strategies. Moreover, continued efforts to restore and protect critical habitats, particularly spawning and nursery areas, are vital for the recovery of Atlantic sturgeon populations. Research on the success of habitat restoration projects, such as dam removals, will provide valuable insights for future initiatives.

Green Sturgeon (*Acipenser medirostris*)

Distribution and Range. The Green sturgeon (*Acipenser medirostris*) is distributed along the Pacific coast of North America, extending from Mexico to southeast Alaska. These fish predominantly inhabit marine and estuarine environments, where they are relatively abundant (Houston, 1988; Moyle et al., 1995). However, their freshwater range has been significantly

reduced due to the construction of dams, which have limited access to traditional spawning habitats in various rivers (Moyle, 2002; St. Pierre & Campbell, 2006).

Conservation Status. Green sturgeon populations have experienced significant declines, primarily due to habitat fragmentation caused by dam construction, which restricts access to vital spawning grounds and alters river flow regimes critical for reproductive success (Moyle, 2002; St. Pierre & Campbell, 2006). Harvest levels of green sturgeon have also decreased dramatically, influenced by more restrictive state regulations and bycatch in commercial fisheries. From 1985 to 1989, the annual harvest was 6,871 fish, which dropped to 1,192 fish by 1999–2001 (St. Pierre & Campbell, 2006). Klamath Tribal fisheries accounted for an average annual catch of 266 adult fish between 1986 and 2001, while bycatch in British Columbia's domestic trawl fishery remains around 171 fish annually (Adams et al., 2002; Davies, 2004).

Unique Life Histories. Green sturgeon are anadromous, migrating from the ocean to freshwater rivers for spawning. Documented spawning occurs in three North American rivers: the Rogue River in Oregon (Erickson et al., 2002; Rien et al., 2001), and the Klamath and Sacramento River systems in California (EPIC, 2001; Adams et al., 2002; Moyle et al., 1992, 1994). Historically, spawning populations existed in the San Joaquin, Eel, South Fork, Trinity, and Umpqua rivers, but they are now believed to be extirpated from these locations (EPIC, 2001; NMFS, 2002).

Status and Threats. Green sturgeon face numerous threats, including habitat fragmentation from dam construction and bycatch in commercial fisheries. These factors have led to significant declines in their populations. Seasonal variations in abundance are observed in several estuaries, such as the Sacramento-San Joaquin, Eel, Columbia, Willapa Bay, Grays Harbor, and Fraser River (Beamesderfer & Webb, 2002). Harvest reductions are attributed to more restrictive regulations, including slot limits that allow the retention of green sturgeon captured as bycatch only if they measure between 122 and 168 cm (St. Pierre & Campbell, 2006). Additionally, the sport catch of green sturgeon in California is minimal, with few fish caught each year (Adams et al., 2002).

Future Research Needs. Significant research is being conducted to better understand the ecology and behavior of green sturgeon, particularly through telemetry studies by organizations such as the U.S. Fish and Wildlife Service, U.C. Davis, California Department of Fish and Wildlife, U.S. Army Corps of Engineers, and the California Department of Water Resources.

These studies focus on juvenile and adult green sturgeon behavior in the Sacramento River, providing valuable insights into their movement patterns and habitat use. However, there remain considerable gaps in our knowledge that future research should prioritize. Studies on habitat preferences and migration patterns are crucial to inform restoration and conservation efforts. Research on reproductive biology, including spawning behaviors, fecundity, and larval development, is needed to better understand reproductive success and challenges. Additionally, investigations into the impact of environmental stressors, such as pollutants, temperature changes, and flow alterations, on green sturgeon health and reproduction are essential for developing effective management strategies. Finally, long-term monitoring of population dynamics and genetic diversity is necessary to assess the effectiveness of conservation measures and identify emerging threats.

Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)

Distribution and Range. The Gulf sturgeon (*Acipenser oxyrinchus desotoi*) is a subspecies of Atlantic sturgeon, inhabits the Gulf of Mexico's coastal waters, ranging from Lake Pontchartrain in Louisiana south to Charlotte Harbor in Florida. Their natal river systems span seven major river basins, including the Pearl River in Louisiana, Pascagoula River in Mississippi, and Suwannee River in Florida, among others (St. Pierre & Parauka, 2006; USGS unpublished data). The total range encompasses approximately 2,500 kilometers of river systems and 1,500 kilometers of coastline.

As with other sturgeon species, the construction of dams, sills, and other water control structures has restricted inland migrations of Gulf sturgeon in many of the aquatic systems they occupy. These barriers prevent access to critical spawning and feeding habitats, significantly impacting their life cycles and population dynamics.

Conservation Status. Gulf sturgeon were listed as threatened under the Endangered Species Act in 1991, with population estimates revealing varied levels of population health across different river systems. The Suwannee River hosts the most viable subpopulation, with an estimated 7,650 to 9,743 individuals larger than 1,000 mm TL (Sulak et al., 2016; USFWS & NMFS, 2022). This subpopulation is notable for containing two genetically distinct stocks, which contribute to the overall abundance estimate. However, more research is needed to determine the population abundance for each independent stock (Zona, 2023; Price et al., 2024,

in review). The Choctawhatchee River has shown consistent estimates of 2,500 to 3,300 individuals since 2007 (USFWS & NMFS, 2022). The Apalachicola River has seen increased estimates since the mid-1980s, with current numbers ranging from 750 to 1,300 adults, though a major hurricane in 2018 significantly impacted the population (Dula et al., 2022). In the Yellow River, estimates range from 398 to 867 adults based on side-scan sonar surveys conducted in 2011 and 2012 (Sulak et al., 2016; USFWS & NMFS, 2022). The Escambia River population was estimated at 372 adults in 2015 (Sulak et al., 2016; USFWS & NMFS, 2022). Finally, the Pearl and Pascagoula rivers have populations estimated at less than 400 individuals greater than 600 mm FL (Rogillio et al., 2001; Ross et al., 2001).

Genetic Diversity. Stabile et al. (1996) examined the genetic diversity of Gulf sturgeon from eight drainages along the Gulf of Mexico, noting significant differences among stocks. Five regional or river-specific stocks were identified. Lake Pontchartrain and Pearl River, Pascagoula River, Escambia and Yellow rivers, Choctawhatchee River, Apalachicola, Ochlockonee, and Suwannee rivers. These genetic distinctions highlight the complexity of Gulf sturgeon populations and underscore the importance of managing each stock separately to maintain genetic diversity and population health.

Threats and Challenges. Similar to other sturgeon species, Gulf sturgeon face a variety of threats and challenges. Dam construction restricts access to vital spawning and feeding habitats, while dredging and dredge spoil disposal disrupt habitats and can cause direct harm to individuals. Water withdrawals, including groundwater extraction and surface water withdrawals for irrigation, alter flow regimes that are critical for sturgeon habitats. Pollution from industrial contaminants adversely affects fish health and reproductive success (St. Pierre & Parauka, 2006). Additionally, natural disasters, such as hurricanes, can lead to significant population declines due to acute mortality events (Dula et al., 2022). To address these challenges, a recovery and management plan for Gulf sturgeon has been developed, identifying necessary state and federal actions to allow for de-listing. This plan includes the designation of "critical habitat" encompassing 2,783 river kilometers and 6,042 square kilometers of estuarine and marine habitat (USFWS & NMFS, 2022).

Future Research Needs. Research on Gulf sturgeon has advanced our understanding of their biology and ecology, but several knowledge gaps remain. Further research is needed to better understand the connectivity between different population segments and its implications for

genetic diversity. Additionally, more studies are required to evaluate the long-term effects of human activities, such as dam construction and pollution, on Gulf sturgeon habitats. Continuous monitoring and assessment are necessary to determine the effectiveness of implemented conservation strategies and to adapt them as needed. While tagging, hydroacoustic surveys, and side-scan sonar surveys have provided valuable insights into migration patterns and habitat use, more data are needed to refine these understandings. Finally, investigations into reproductive biology have confirmed spring and fall spawning events driven by distinct genetic stocks in certain rivers, highlighting the need for further research to fully understand these dynamics.

Lake Sturgeon (*Acipenser fulvescens*)

Distribution and Range. Lake sturgeon (*Acipenser fulvescens*) are widely distributed across North America, residing exclusively in freshwater environments. Their historical range spans the Mississippi River and tributaries, the Great Lakes, Lake Champlain, the St. Lawrence River, Hudson Bay-James Bay, and the Saskatchewan River (Pflieger, 1975; Becker, 1983; Ferguson & Duckworth, 1997). In the Mississippi Basin, lake sturgeon are currently found from Minnesota's headwaters to northern Louisiana, extending up the Missouri River into southern South Dakota, and the Ohio River as well as major tributaries such as the White River (Indiana) and Cumberland and Tennessee rivers. There is no known natural exchange of stocks between the Great Lakes and western Canadian provinces and those of the Mississippi River basin, although some stockings in the Mississippi River basin have included lake sturgeon of Great Lakes Basin origin.

Conservation Status. The IUCN SSC Sturgeon Specialist Group assessed the conservation status of lake sturgeon as Endangered in 2019, with sub-population statuses ranging from Critically Endangered to Least Concern (Haxton & Bruch, 2022). Populations in the Mississippi-Missouri River Basin and the Great Lakes-St. Lawrence River Basin are significantly reduced from historical levels, though most populations are considered stable. Lake sturgeon, like other sturgeon species, grow slowly, mature late, and are intermittent spawners, making them particularly susceptible to over-exploitation. However, there are areas, such as Lake Winnebago, WI; Black Lake, MI; and the St. Clair River, MI, where local populations are stable enough to support limited recreational fishing. In 2024, the U.S. Fish and Wildlife Service announced that

following a species status assessment that the Lake Sturgeon would not be listed under the Endangered Species Act due to ongoing collaborative conservation efforts across many states.

Unique Life Histories. Lake sturgeon have unique life history traits that make them particularly vulnerable to overharvest and habitat degradation. These fish grow slowly, mature late, return to their natal streams to spawn, and are intermittent spawners. These characteristics, combined with their specific habitat requirements often spread across large home ranges, contribute to their sensitivity to environmental changes and human activities.

Status and Threats. Lake sturgeon populations face significant threats primarily due to anthropogenic activities. Industrial pollution, dredging of shallow spawning sites, and sedimentation have led to the destruction or removal of critical habitats (Rochard et al., 1990; Auer, 1996; Beamesderfer & Farr, 1997; Noakes et al., 1999). Additionally, dams and channelization reduce or eliminate habitat connectivity, which is crucial for accessing spawning and feeding areas. The alteration of river flows and the creation of reservoirs further threaten lake sturgeon subpopulations (Hondorp et al., 2017). Another concern is the direct mortality of lake sturgeon due to collisions with commercial and recreational vessels, although the frequency of fatal strikes remains unknown (Hondorp et al., 2017). Climate change poses an emerging threat, potentially affecting habitat quality and migration timing. Warming waters can disrupt the temporal overlap of different phenotypes on shared spawning grounds, thereby impacting intraspecific diversity (Embke et al., 2023; Buchinger et al., 2022). Lake Sturgeon are also considered a coolwater species and research has suggested that warming temperatures in the summer that approach their critical thermal maxima may make some habitats unsuitable, alter movement behaviors, and lead to physiological stress (Lyons & Stewart 2014; Bugg et al., 2020; Moore et al., 2021; Moore et al., 2022).

Future Research Needs. Ongoing research and conservation efforts are critical for the future of lake sturgeon populations. One key area of focus is the construction of artificial reefs to remediate spawning area losses, particularly in the St. Clair and Detroit rivers, where over 8 hectares of rock spawning reefs were created between 2004 and 2018 (McLean et al., 2014; Roseman et al., 2017; Manny et al., 2015; Vaccaro et al., 2016; Fischer et al., 2018, 2020, 2021). However, the impact of these restored spawning habitats on lake sturgeon production remains uncertain due to challenges in linking individuals to specific natal habitats (Hondorp et al., 2014). In addition to habitat restoration, upstream transfer of lake sturgeon during spawning

season has shown promise in rivers where dam passage is impossible (Iserman et al., 2022). Research into the genetic and environmental influences on migration strategies is ongoing, providing significant insights into these dynamics (Whitaker et al., 2018; Buchinger et al., 2023b). Climate adaptation approaches are also being emphasized, particularly in planning and implementing habitat restoration in the Great Lakes region (Embke et al. 2023). Furthermore, reintroduction efforts are underway in several rivers with historical lake sturgeon populations, including the Cuyahoga, Maumee, and Sandusky rivers in Ohio, the Saginaw River system in Michigan, Missouri River in Missouri, Tennessee River in Tennessee and Cumberland River in Tennessee and Kentucky, Coosa River in Georgia. However, questions remain regarding the survival of stocked juveniles, time to maturation, and return to natal or stocked rivers (McKenna, 2023; Moore et al. 2022a).

Pallid Sturgeon (*Scaphirhynchus albus*)

Distribution and Range. The pallid sturgeon (Scaphirhynchus albus) inhabits approximately 5,656 river kilometers, including the Missouri River, Lower Yellowstone River, Lower Platte River, and the Mississippi River near its confluence with the Missouri River, extending downstream to the Gulf of Mexico. This range also includes the Atchafalaya River in central Louisiana (Krentz, 2004; Reed & Ewing, 1993; USFWS, 2007). Additionally, pallid sturgeon have been documented near the mouths of other large tributaries of the Mississippi River, likely due to short-term flow conditions (USFWS, 1989). Historically, their range was cited as "more than 6,000 km" (Jordan et al., 2016).

Conservation Status. Pallid sturgeon were listed as endangered under the Endangered Species Act (ESA) in 1990. The primary reasons for their listing include habitat modification and fragmentation, alteration of flow and temperature regimes, illegal harvest, and hybridization with the more common shovelnose sturgeon. Since being listed as endangered, considerable research has been conducted to identify habitat occupancy and assess habitat needs and behaviors. Pallid sturgeon are also listed on CITES Appendix II.

Unique Life Histories. Pallid sturgeon exhibit unique potamodromous life history characteristics, including immediate downstream drift upon hatching and dispersal until endogenous feeding begins, which requires hundreds of miles of open river. Spawning has been documented in the Missouri, Yellowstone, and Platte rivers using telemetry, reproductive

assessments, and the collection of drifting free embryos. On the Yellowstone River, pallid sturgeon have been observed spawning in aggregations on sand dunes and small gravel patches (DeLonay et al., 2016). Similarly, in the channelized Lower Missouri River, pallid sturgeon spawn on bank revetment, bedrock, and sand dunes on outside bends in deep and fast water (Elliott et al., 2020).

Status and Threats. Population trends for pallid sturgeon range from decreasing to functionally extirpated in the upper part of their range to stable, but highly introgressed, in the lower part of their range. However, the population and status of pallid sturgeon in the middle portion of their range remain largely unknown (Krentz, 2004), believed to be the only remaining population of reproducing and recruiting pure pallid sturgeon. The construction of dams has significantly altered the flow and temperature regimes and reduced turbidity in the Missouri River, with extensive channelization in the lower Missouri and Mississippi rivers being primary factors affecting the recovery of Pallid Sturgeon. On the Upper Missouri River, dam construction has limited the length of river available for free embryo drift and development. Recovery actions are identified in the Pallid Sturgeon Recovery Plan (Dryer & Sandvol, 1993).

Future Research Needs. Future research should focus on understanding the population size and status of Pallid Sturgeon in the middle portion of their range, which remains largely unknown. Additional studies are needed to further explore the impacts of habitat modification, flow alteration, and hybridization on Pallid Sturgeon populations. Research on the effectiveness of current conservation and recovery strategies, as well as the development of new approaches to mitigate threats, will be critical to ensuring the survival of this endangered species.

Shortnose Sturgeon (*Acipenser brevirostrum*)

Distribution and Range. The shortnose sturgeon (*Acipenser brevirostrum*), one of North America's smallest sturgeon species, typically reaches lengths of 3-4 feet and weights of 10-15 pounds. This species is characterized by a short, rounded snout and five rows of bony plates, or scutes, along its body. Historically, the shortnose sturgeon's range included many large coastal rivers of eastern North America, from the Saint John River in New Brunswick, Canada, to at least the St. Johns River in Florida (Dadswell et al., 1984; Kynard, 1997). However, the southernmost rivers, such as the Satilla and Saint Mary’s rivers in Georgia and the Saint Johns River in Florida, do not support spawning populations. Currently, reproducing shortnose

sturgeon populations range from the Saint John River in New Brunswick to the Altamaha River in Georgia, with more abundance in the northern and mid-Atlantic regions compared to southern populations due to watershed characteristics (Rogers & Weber, 1995; Wirgin et al., 2010; Collins et al., 2000).

Conservation Status. The shortnose sturgeon is listed as "vulnerable" on the IUCN Red List of Threatened Species and is protected under Appendix I of CITES (Wirgin et al., 2010). In Canada, it is classified as a "species of special concern" under COSEWIC (2005). In the United States, the species was originally listed as endangered in 1967 and again in 1973 under the Endangered Species Act (ESA). Population estimates vary, with approximately 60,000 adult sturgeon in the Hudson River, New York (Bain, 2001), and less than 100 in the Merrimack River, Massachusetts (Kieffer & Kynard, 1993). However, recent estimates suggest about 3,500 adults in the Merrimack River (Steel Associates). Other rivers, such as the Saint John River, Kennebec River system in Maine, Connecticut River in Connecticut and Massachusetts, Delaware River in New Jersey and Pennsylvania, Savannah River in South Carolina and Georgia, and Altamaha River, have populations exceeding 1,000 adults, a critical threshold for population viability (Thompson, 1991; Wirgin et al., 2010). Despite recommendations for downlisting certain populations, no shortnose sturgeon population has been downlisted to date (NMFS, 1998b).

Unique Life Histories. Shortnose sturgeon exhibit distinct life histories influenced by the environmental variation in the river systems they occupy across their range. Their limited size and specific habitat requirements, including the need for access to both upstream spawning grounds and downstream feeding areas, make them particularly vulnerable to environmental changes. These unique life history traits, combined with their limited range, have made them a focus of conservation efforts aimed at preserving their populations across North America.

Status and Threats. The primary threats to shortnose sturgeon, similar to other sturgeon species, stem from dam construction, which impedes up- and downstream migrations, causes habitat loss or degradation, and alters flow and water temperature regimes. Additional significant threats include in-river channel maintenance, such as dredging, and pollution (Friedland & Kynard, 2004). Southern populations face particular risks due to water withdrawals and eutrophication. Direct mortality sources include impingement on water intake screens, dredging, and incidental capture in other fisheries (NMFS, 1998b). While incidental harvest with Atlantic

sturgeon is possible in Canada, there are no legal fisheries or by-catch allowances for shortnose sturgeon in U.S. waters (Friedland & Kynard, 2004).

Future Research Needs. Future research on shortnose sturgeon should focus on understanding the species' response to ongoing environmental changes, such as climate change and habitat modification, to inform conservation strategies. Additionally, studies are needed to explore the effectiveness of current protection measures and to develop new strategies to mitigate threats from human activities. Research on the genetic diversity and connectivity between populations could provide insights into the resilience of the species and inform efforts to bolster vulnerable populations.

Shovelnose Sturgeon (*Scaphirhynchus platorynchus*)

Distribution and Range. Shovelnose sturgeon (*Scaphirhynchus platorynchus*) are distributed throughout the Mississippi and Missouri rivers, including the lower Ohio River (Smith, 1979). They are found in most of the large tributaries of the Upper Mississippi River, from Wisconsin to Illinois (Surprenant, 2004). They also occur in the Arkansas River system into Oklahoma. Historically, shovelnose sturgeon occupied 59 rivers, creeks, oxbows, and bayous in the Mississippi River Basin. Shovelnose Sturgeon historically occupied the Rio Grande and Mobile basins but have been extirpated from these portions of their range. However, recent surveys indicate that they are currently supported in only 44 of these waterways (Hesse & Carreiro, 1997). Their presence is now sporadic in the lower Tennessee and Cumberland Rivers (Etnier & Starnes, 1993), but they remain most abundant in the Wabash River, Illinois (Smith, 1979).

Conservation Status. The U.S. Fish and Wildlife Service classified shovelnose sturgeon as threatened due to their similarity in appearance to the endangered pallid sturgeon (United States Federal Register, 2010). This listing was justified under the similarity of appearance provisions of the Endangered Species Act (ESA). Additionally, the International Union for Conservation of Nature (IUCN) lists shovelnose sturgeon as "vulnerable" (Surprenant, 2004). The IUCN designation is based on a range reduction of approximately 30% and a projected population size reduction of 30% or more within the next 10 years or three generations, primarily due to actual or potential levels of exploitation (Surprenant, 2004).

Unique Life Histories. Shovelnose sturgeon, like other sturgeon species, exhibit unique life histories, including extensive spawning migrations. These migrations have been historically

essential for accessing diverse spawning grounds across their range. However, the construction of dams has significantly disrupted these patterns, leading to isolated populations and a loss of genetic diversity. The species' resilience is further tested by changes in river flow, turbidity, and temperature, which directly affect their reproductive success and survival (Dryer & Sandvol, 1993).

Status and Threats. The decline of shovelnose sturgeon has been significantly influenced by the construction of locks and dams for navigation, which block access to ancestral spawning grounds. Similar to other sturgeon species, dams have impeded spawning migrations, resulting in isolated populations, degraded rearing and spawning habitats, and altered flow, turbidity, and temperature regimes (Dryer & Sandvol, 1993). Additionally, water withdrawals for irrigation and public water supply have further impacted shovelnose sturgeon habitats (Surprenant, 2004). These combined factors have led to a significant reduction in the species' range and population. Climate change may be an additional threat to southern populations in shallow rivers as water temperatures exceeding 30 degrees C have been implicated as potential causes of mass mortality events of shovelnose sturgeon (Hupfeld et al., 2015; Deslauriers et al., 2016).

Future Research Needs. To effectively conserve shovelnose sturgeon, future research needs to focus on restoring connectivity in river systems to facilitate spawning migrations. Studies should also examine the impact of altered river flows on sturgeon life cycles and explore the genetic diversity of isolated populations to inform conservation strategies. Additionally, research on the potential effects of climate change on river ecosystems and sturgeon habitats will be crucial for long-term species survival. Effective management and conservation efforts will require a comprehensive understanding of these factors to mitigate ongoing threats and ensure the persistence of shovelnose sturgeon populations.

White Sturgeon (*Acipenser transmontanus*)

Distribution and Range. The range of white sturgeon (*Acipenser transmontanus*) spans the estuaries, rivers, and near-shore environments of the Pacific coast from Alaska to Baja California. They primarily spawn in the Columbia-Snake River system, Fraser River, and Sacramento-San Joaquin River. The largest populations of white sturgeon are found along the west coast of the United States, particularly within the Sacramento-San Joaquin and Columbia-Snake River basins. Additional populations exist in the Kootenai River in the United States and

Canada (Paragamian et al., 1997), the Fraser River drainage in Canada (RL&L Environmental Services Ltd., 2000), and the Columbia River between Hugh Keenleyside Dam and the Canada-U.S. border (Duke et al., 2004). While populations are considered stable in the lower reaches of the Columbia River (Hildebrand et al., 1999; Parsley et al., 2002), declines have been observed in the Sacramento-San Joaquin estuary (Kolhorst, 1995). In Canada, the most abundant populations are found in the Fraser River system.

Conservation Status. White sturgeon are listed on CITES Appendix II, highlighting their need for international trade control to prevent exploitation. In 1994, the population in the U.S. portion of the Kootenai River was listed as endangered under the Endangered Species Act. To address the conservation needs of this population, a recovery plan was developed by a team of Canadian and American scientists (Duke et al., 1999). This plan focuses on conservation measures aimed at recovering the Kootenai River white sturgeon population, with objectives including the establishment of successful wild reproduction through flow management and stocking hatchery-reared juveniles.

Unique Life Histories. The construction of hydroelectric dams within the Columbia River basin, starting in 1933, has led to the isolation of white sturgeon populations above these barriers. Presently, there are 17 landlocked subpopulations upstream of Bonneville Dam, the furthest downstream dam on the Columbia River, including the tributary Snake River (DeVore et al., 1993). The productivity of these landlocked subpopulations varies significantly; some support high populations and sustainable fisheries (DeVore et al., 1999; North et al., 1999), while others sustain no exploitation due to low recruitment and productivity (PSMFC, 1992).

Status and Threats. Despite advancements in understanding white sturgeon ecology, significant threats persist, particularly from habitat fragmentation and contaminants. Hydroelectric development has resulted in population isolation, with varying levels of productivity among landlocked subpopulations. Additionally, contaminant-related issues, especially from mining activities, pose significant threats. These contaminants can affect different life stages, developmental processes, and behavior, ultimately impacting recruitment and water quality (Werner et al., 2012; Guilherme et al., 2018; Kolok et al., 2013; Martins et al., 2015). Broader impacts of pollutants on aquatic ecosystems further compound these challenges (McCarthy et al., 2014; Johnson et al., 2012; Chen et al., 2014).

Future Research Needs. Future research should prioritize assessing population health to determine the viability and genetic diversity of different white sturgeon populations. Identifying and protecting spawning habitats crucial for successful reproduction is essential, along with evaluating the effectiveness of current conservation measures, including habitat restoration and management practices. Additionally, investigating the effects of contaminants on different life stages and their behavioral impacts, particularly in relation to water quality, is critical. Broader studies on the impacts of pollutants on aquatic ecosystems are also necessary to address significant research gaps related to contaminant exposure (Adams et al., 2013; Werner et al., 2012; Guilherme et al., 2018).

SECTION 3: USGS SCIENCE VISION FOR STURGEON AND PADDLEFISH RESEARCH IN THE UNITED STATES

INTRODUCTION

In this section, we outline a set of specific strategic research priorities for addressing research needs specific to sturgeon and paddlefish science and structured around a set of key research themes and subsequent focal research areas. The section is divided into specific research categories, including life history, ecology, threats, and habitat requirements, as well as the development of decision-support tools. Each category contains focal areas that detail research directions for USGS, including advancing genomic studies, improving habitat connectivity, and enhancing collaborative efforts to protect these species.

Often referred to as "living fossils," sturgeons and paddlefish have survived for millions of years but now face unprecedented threats from human activities. Significant advances in understanding sturgeon and paddlefish biology have revealed critical gaps in our knowledge of their life histories, population dynamics, and responses to environmental changes. A focused research vision helps USGS prioritize studies that address these gaps, helping to advance conservation efforts based on the best available science.

This vision is also a tool for guiding conservation efforts by providing an agency-specific research roadmap for assisting in identifying key habitats, assessing population health, and

implementing measures to mitigate threats such as habitat destruction, pollution, and climate change. Enhancing policy and management is another key aspect, as policymakers and resource managers rely on scientific evidence to make informed decisions. A comprehensive research vision ensures that USGS research outputs are relevant and actionable and helps lay the scientific foundation for others to develop policies and management plans that promote the long-term sustainability of sturgeon and paddlefish populations.

Moreover, the vision promotes adaptive management, acknowledging that ecosystems are dynamic and continuously changing due to natural and human-induced factors. By guiding an adaptive management approach, this research vision allows for the continuous refinement of research strategies based on new scientific findings and changing environmental conditions. Fostering innovation and technological advances is a key objective, encouraging the development and application of innovative technologies and methodologies—such as genetic analyses, telemetry, and remote sensing—to improve our understanding and management of these species. Finally, the need for data and information exchange and integration is emphasized, ensuring that scientific findings are shared across institutions, agencies, and stakeholders to create a coordinated approach to sturgeon and paddlefish conservation science. We feel this collaborative effort is essential for filling critical knowledge gaps, informing decision-making, and effectively managing the conservation of these imperiled species in a rapidly changing environment.

COLLABORATION AND STAKEHOLDER ENGAGEMENT

The success of sturgeon and paddlefish conservation efforts relies heavily on robust collaboration and active engagement with a diverse array of stakeholders and rightsholders. The USGS recognizes that addressing the complex challenges facing these species requires the collective expertise, resources, and commitment of various partners, including federal and state agencies, Tribal organizations, non-governmental organizations, academic institutions, and the private sector.

Collaboration with state, federal, and provincial agencies is crucial for aligning research priorities and conservation efforts across different jurisdictions. Joint initiatives, such as population and habitat monitoring programs led by interstate fisheries commissions, benefit from the combined resources and expertise of multiple agencies, resulting in more effective and

cohesive conservation outcomes. Engaging with Tribal organizations is equally important, as indigenous communities have a deep cultural and ecological connection to sturgeon and paddlefish. Integrating traditional ecological knowledge into research and management practices enriches our understanding of these species and fosters respectful and inclusive conservation efforts. Non-governmental organizations (NGOs) play a pivotal role in advocacy, public education, and on-the-ground conservation work. Partnering with NGOs enhances the outreach and impact of USGS research, mobilizing public support and additional resources for sturgeon and paddlefish conservation.

Academic institutions contribute valuable scientific expertise and innovative research methodologies. Collaborative research projects with academic partners facilitate knowledge exchange, provide training opportunities, and advance cutting-edge science. Engaging with the private sector, including industries such as fisheries, agriculture, and hydropower, is crucial for addressing threats to sturgeon and paddlefish habitats. Collaborative efforts with industry stakeholders can lead to the development of sustainable practices and technologies that minimize the environmental impact of industrial activities. Finally, sturgeon and paddlefish conservation is a global challenge, particularly for species that cross international boundaries. The USGS actively engages in international collaborations to share knowledge, harmonize conservation strategies, and address transboundary threats.

USGS STURGEON AND PADDLEFISH RESEARCH THEMES

RESEARCH CATEGORY 1: LIFE HISTORY AND ECOLOGY

FOCAL RESEARCH AREA 1A:

EARLY AND LATE LIFE HISTORIES, PHYSIOLOGY, AND REPRODUCTION

Introduction: Sturgeon and paddlefish, often called "living fossils," are ancient, long-lived fish species with roots dating back to the time of dinosaurs. Both species are ecologically significant in North America, contributing to nutrient cycling in their aquatic environments. Sturgeon, known for their slow growth and longevity—sometimes exceeding a century—are

migratory, moving between freshwater and saltwater. Their cartilaginous skeletons and sucker-like mouths enable bottom feeding in rivers and lakes, and they can survive low oxygen levels, which is crucial during their long migrations to spring spawning sites. Conservation efforts for sturgeons have mostly focused on protecting critical spawning habitats and controlling overfishing. Paddlefish, with their distinctive paddle-shaped snout, filter-feed on zooplankton and small invertebrates. They have shorter lifespans, typically 20 to 30 years, and their reproduction involves unique spawning behaviors, using electroreceptors on their rostrum to detect prey in murky waters. Conservation efforts for paddlefish emphasize protecting spawning grounds and managing water quality to ensure their survival.

USGS Efforts to Date. The USGS has made significant strides in understanding the early and late life histories, physiology, and reproduction of sturgeon and paddlefish. Research efforts have focused on the development and survival of sturgeon larvae, the physiological adaptations that allow sturgeons to thrive in various environments, and the complex reproductive behaviors that ensure the continuation of these species. Studies have detailed the migratory patterns and spawning behaviors of sturgeons, highlighting the critical need for access to specific spawning habitats. In addition, USGS research has explored the unique adaptations of paddlefish, including their electroreceptors and filter-feeding mechanisms, which are crucial for their survival in large river systems. The agency's work has also addressed the impacts of environmental changes, such as habitat fragmentation and water quality degradation, on the reproductive success and overall health of these species.

Desired Future Directions. Looking ahead, the USGS aims to expand its research on the physiological responses of sturgeon and paddlefish to environmental stressors, particularly in the context of climate change and pollution. This includes a deeper exploration of how these stressors interact and impact reproductive success, larval development, and survival rates. Basic research on age estimation, which informs hatch estimation, growth, and longevity, is lacking for many species in part because of the lack of suitable aging structures. Otoliths of these species represent an ancient adaptation and are difficult to interpret and more integrated research may make these structures more suitable. Additionally, identification of post-larval age-0 movements and habitat connectivity needs is a knowledge gap, including how the typically assumed locations (e.g., river mouths), with the associated high disturbance and lower quality environmental conditions, impact foraging, survival, and recruitment. There is also a need to

enhance understanding of the genetic diversity within and among sturgeon and paddlefish populations, which is critical for developing effective conservation strategies. Additionally, the USGS seeks to advance the development of innovative technologies, such as telemetry and remote sensing, to monitor these patterns and support the conservation of these ancient and ecologically significant species.

FOCAL RESEARCH AREA 1B:

DISTRIBUTIONS, HABITAT USE, AND HABITAT SUITABILITY

Introduction: North American sturgeon and paddlefish inhabit a variety of freshwater and seawater systems, including large rivers, lakes, estuaries, and coastal areas across the continent. These species exhibit distinct habitat use patterns throughout their life stages, with young fish typically occupying shallow, near-shore nursery areas where food is plentiful and predation risks are reduced. As they mature, sturgeon and paddlefish transition to deeper, open-water habitats, which offer access to preferred prey and suitable breeding conditions. Sturgeon are known for their extensive migrations to specific river systems to spawn. Despite the importance of these inland water habitats, marine and large lake environments also play a crucial role, providing essential foraging grounds and migratory routes for many sturgeon species. Habitat degradation and pollution significantly impact the distribution and habitat use of North American sturgeon and paddlefish. Industrial pollutants and agricultural runoff have deteriorated water quality in many rivers and lakes, adversely affecting the species' spawning and feeding grounds. Additionally, the construction of dams has drastically altered natural habitats by obstructing migratory routes, preventing access to traditional spawning sites, and fragmenting populations. This forces sturgeon to spawn in suboptimal locations, reducing reproductive success and juvenile survival rates. Overfishing has also led to severe population declines in sturgeon and paddlefish, particularly through the overharvesting of adults for their roe.

Sustainable fishing practices and stringent regulations are critically needed to protect these vulnerable populations. Juvenile habitats, typically in shallow, near-shore areas, provide essential resources for the early life stages of these species. As sturgeon and paddlefish mature, their migration to deeper waters is vital for accessing preferred prey and for successful breeding,

ensuring genetic diversity and population connectivity. The unique ecological requirements of sturgeon in marine waters highlight the need for comprehensive habitat conservation strategies that address both freshwater and marine ecosystems. The survival and recovery of these species depend on protecting critical habitats, improving water quality, and mitigating the impacts of dams and other barriers.

USGS Efforts to Date. The USGS has conducted significant research on the distribution, habitat use, and habitat suitability of North American sturgeon and paddlefish, focusing on understanding the critical habitats and the impacts of environmental factors. Key studies have addressed the effects of habitat degradation, pollution, and dam construction on migratory patterns and reproductive success. For example, USGS research has demonstrated how industrial pollutants and agricultural runoff contribute to the deterioration of spawning and feeding grounds, negatively impacting water quality and sturgeon populations. Additionally, dam construction has been shown to obstruct migratory routes, forcing sturgeon to spawn in suboptimal conditions, thus reducing juvenile survival rates (Gilligan-Lunda, Duarte, & Peterson, 2024; Haxton, Sulak, & Hildebrand, 2016). Habitat selection studies have further highlighted the critical importance of temporal, spatial, and ontogenetic variation for restoration efforts, emphasizing how sturgeon populations adapt to different environments and life stages (Moore, Paukert, Owens, & Moore, 2024). USGS studies have also emphasized the importance of near-shore habitats for juvenile sturgeon, which play a crucial role in species survival. Overfishing has further compounded the problem, as it has led to the depletion of mature sturgeon populations, reinforcing the need for sustainable fishing practices. Moreover, the marine environments, crucial for foraging and migration, are being studied for their role in the overall health and survival of these species (Dale et al., 2021).

Desired Future Directions. Looking forward, the USGS aims to enhance its research on habitat suitability by developing more refined models that integrate both freshwater and marine ecosystems. Future research will focus on expanding the understanding of habitat requirements across all life stages of sturgeon and paddlefish, with particular attention to the impacts of climate change, pollution, and habitat fragmentation. The USGS plans to prioritize studies that evaluate the effectiveness of current habitat restoration efforts, particularly in areas impacted by dam construction. This includes investigating the potential for improving fish passage facilities and other mitigation strategies that could enhance connectivity between fragmented populations.

Moreover, there is a need to explore the role of marine habitats more deeply, ensuring that conservation strategies encompass the entire range of environments that sturgeon and paddlefish utilize. Finally, the USGS seeks to advance collaborative efforts with federal, state, tribal, and international partners to develop comprehensive management plans that address both immediate and long-term conservation challenges. This will involve integrating traditional ecological knowledge with scientific research to create more inclusive and effective conservation practices.

FOCAL RESEARCH AREA 1C:

GENOMIC ANALYSES AND POPULATION VIABILITIES

Introduction: Genomics, encompassing DNA sequencing, nuclear DNA content analysis, genotyping, and gene analysis, has revolutionized our understanding of sturgeon and paddlefish species. Researchers utilize these advanced genomic techniques to explore various aspects of these species, including individual species identification, hybrid delineations, population structures, genetic diversity, and adaptive traits. These insights are critical for understanding species presence, evolutionary history, and the potential for adaptation to changing environmental conditions. Genomic research plays a pivotal role in informing conservation strategies, such as captive breeding programs, habitat restoration, and sustainable harvest management. Additionally, Population Viability Analysis models are essential tools that integrate genetic data, life history information, and environmental factors to assess the long-term viability of sturgeon and paddlefish populations. These models predict the likelihood of population persistence and guide conservation efforts. Understanding the genetic diversity and adaptive potential of these species is crucial for their conservation, especially in the face of ongoing environmental changes and human activities. Whole genome sequencing of species like the American paddlefish and Chinese sturgeon has provided new insights into chromosomal evolution and the complex genomic history of these species, aiding in more informed conservation decisions (Cheng et al., 2020; Wang et al., 2023). Additionally, there are optimized cryopreservation techniques for germline stem cells, which are critical for the long-term preservation and restoration of sturgeon and paddlefish species, supporting the conservation of critically endangered populations (Ye et al., 2020).

USGS Efforts to Date. USGS scientists have made significant strides in genomic research to support the conservation of sturgeon and paddlefish, achieving key milestones that enhance conservation strategies. These accomplishments include the development of genetic identification techniques, enabling the identification of Acipenseriform embryos approximately 24 hours after fertilization, which is crucial for monitoring spawning in imperiled sturgeon species (Kashiwagi et al., 2020). USGS researchers also developed new microsatellite markers and over 11,000 microhaplotyped loci markers, providing high-resolution differentiation between pallid and shovelnose sturgeon, essential for managing hybridization threats (Flamio Jr. et al., 2021; Flamio Jr. et al., 2022). To address polyploidy challenges, USGS developed methods for producing pallid sturgeon specimens with 100% homozygous DNA from the maternal parent, aiding in SNP marker development and accurate genetic analysis (Flamio Jr. et al., 2021). Parentage analysis has been used for lake sturgeon to determine the number of successful breeders, larval dispersal, and genetic connectivity on newly constructed spawning habitat to evaluate the potential impacts to recruitment and population-level genetic diversity (Hunter et al. 2020). Research has also revealed significant genetic differentiation and low genetic diversity in various sturgeon populations, such as the genetic gradient in Columbia River white sturgeon due to hydroelectric dams, underscoring the importance of considering genetic structure in conservation efforts (Willis et al., 2022).

Desired Future Directions. Moving forward, the USGS aims to build on these genomic advancements by pursuing several key directions. First, the USGS plans to integrate more sophisticated genomic data into Population Viability Analysis models to enhance predictions of population persistence under varying environmental conditions. This approach will involve incorporating adaptive traits and genetic diversity metrics, providing more accurate guidance for conservation efforts. Additionally, the USGS is committed to expanding genomic resources by developing additional genetic markers and whole genome sequences. These tools will enable more comprehensive studies on the genetic health and evolutionary potential of sturgeon and paddlefish populations, particularly in response to climate change and habitat fragmentation. The application of genomics in captive breeding programs is another priority, with the goal of using genomic insights to maintain genetic diversity and prevent inbreeding depression in these programs. Furthermore, the USGS will continue to innovate in techniques such as germ cell transplantation and cryopreservation, which are critical for restoring and preserving genetic

diversity in critically endangered sturgeon and paddlefish populations. Finally, the USGS seeks to foster collaborative research initiatives by partnering with other research institutions, conservation organizations, and international stakeholders. These collaborations will advance genomic research and ensure that these findings are applied to global sturgeon and paddlefish conservation efforts.

FOCAL RESEARCH AREA 1D:

PASSAGE BEHAVIOR AND MIGRATIONS

Introduction: Sturgeon and paddlefish are known for their extensive long-distance migrations, often exceeding 300 kilometers, primarily associated with spawning movements that occur in the spring and for some species, also fall. However, the construction of navigation locks and dams along major river systems has fragmented these large rivers, significantly limiting the natural migratory pathways of these species. The presence of these barriers has fundamentally altered the natural migration patterns of sturgeon and paddlefish, with significant implications for their reproduction and population dynamics (Jager et al., 2016; Tripp et al., 2019; Tripp et al., 2020). The extent to which migrations are restricted varies across different structures, with potential pathways for fish passage including gated portions of dams, spillways, or lock chambers. These human-made structures disrupt the historical migration routes, affecting the ability of these species to reach critical spawning and feeding habitats, thus posing a threat to their long-term survival.

USGS Efforts to Date. The USGS has conducted extensive research on the passage behavior and migrations of sturgeon and paddlefish, with a focus on the challenges posed by navigation locks and dams. Studies on lake sturgeon and paddlefish at Mississippi Lock and Dam 19 have shown that upstream passage is restricted to the lock chamber, while downstream passage can occur over the gated portion of the dam (Fritts et al., 2021). Similarly, research at Mississippi Lock 15 revealed that upstream passage for paddlefish is facilitated through the dam gates or the lock chamber, depending on hydraulic conditions (Turney et al., 2022). Ongoing studies in the upper Mississippi River have observed large-scale paddlefish migrations in response to varying conditions such as low-flow, flood, and open-river scenarios (Fritts et al., accepted to Scientific Reports). USGS, in collaboration with the U.S. Army Corps of Engineers (USACE), is also

evaluating fishway designs at Lock and Dam 22 to assess their effectiveness for species like lake sturgeon, shovelnose sturgeon, and paddlefish. Research has indicated that lock and dam operations periodically impact lake sturgeon movements in the Mississippi River (Knights et al., 2002), and a review of dam passage on the Ohio River suggests that dams could affect the upstream movement of lake sturgeon, shovelnose sturgeon, and paddlefish, particularly during certain times of the year (Knights et al., 2003). Detailed studies on paddlefish movements in the Upper Mississippi River, including pools 8, 5A, and multiple tributaries, have highlighted extensive migrations within these regions (Zigler et al., 1997; Zigler et al., 2002; Zigler et al., 2003). Additionally, research on paddlefish exploitation in Missouri reservoirs has provided insights into the pressures these species face from fishing and other human activities (Broaddus, 2020). Recent findings on the sprinting performance and behavior of adult shortnose sturgeon demonstrated that these sturgeons can swim at greater speeds than previously predicted, which has important implications for fishway design parameters (Castro-Santos et al., 2024). USGS, in collaboration with the USACE, is evaluating adult and juvenile green sturgeon movements in the Sacramento River and found migration timing of both life stages to be positively influenced by river flow (Hansen et al., 2022; Hansen et al., 2024). The USGS also investigated the impact of captive sturgeon on remaining wild populations, concluding that while culture and propagation can play a positive role, there are significant risks, many of which are already being observed in various areas (White et al., 2023).

Desired Future Directions. Building on foundational studies, the USGS has identified several key areas for future research to address ongoing challenges and improve conservation outcomes for sturgeon and paddlefish. These include investigating the anthropogenic and environmental factors influencing the timing and success of passage at navigation locks and river systems, which will optimize passage designs and management practices. Additionally, research should assess the impact of fishways and aquatic invasive species deterrents on sturgeon and paddlefish movements to ensure that conservation measures do not inadvertently harm these species. Further studies are needed to examine changes in habitat use and harvest patterns over time, particularly in response to environmental changes and management interventions, which are crucial for adaptive management strategies. With the increasing impact of climate change, understanding how changing hydrologic conditions and extreme weather events affect migration patterns is essential. Analyzing transition and survival probabilities as sturgeon and paddlefish

move between management zones within the Mississippi River basin will help refine conservation strategies and reduce mortality rates. Identifying high exploitation zones is critical for enhancing management awareness and implementing protective measures. Lastly, developing predictive models that describe movement patterns at various scales will improve the ability to anticipate and mitigate the effects of environmental changes and human activities on sturgeon and paddlefish migrations.

FOCAL RESEARCH AREA 1E:

CULTURE AND PROPAGATION

Introduction: The study and practice of sturgeon culture and propagation are vital for the conservation and restoration of these ancient fish species, which have faced significant declines due to overfishing, habitat loss, and pollution. Culture and propagation efforts are mostly focused on enhancing natural populations and supporting sustainable fisheries, playing a critical role in ensuring the survival of sturgeon species. These practices involve breeding sturgeon in controlled environments, releasing them into the wild to bolster declining populations, and managing hatchery programs to sustain genetic diversity and population health. The USGS has been at the forefront of advancing knowledge in sturgeon culture and propagation, contributing to both the scientific understanding and practical implementation of these conservation efforts.

USGS Efforts to Date. The USGS has made significant contributions to understanding sturgeon culture and propagation through various research initiatives. For example, minimally invasive techniques such as sonography and endoscopy have been developed to estimate the gonadosomatic index (GSI) and fecundity of endangered species like the pallid sturgeon, allowing researchers to gather critical reproductive data without harming the fish. These methods have been successfully applied to both shovelnose and pallid sturgeons to better understand their reproductive cycles (Bryan et al., 2007; Albers et al., 2013). Moreover, the use of non-lethal stable isotope analysis has enabled scientists to assess the feeding patterns of juvenile sturgeon without needing to sacrifice the animals. This technique has provided valuable insights into the diets of juvenile pallid sturgeon, which is essential for optimizing propagation and conservation efforts. These innovative methods have significantly enhanced the ability to manage sturgeon

populations, contributing to more sustainable propagation programs and improved conservation outcomes.

Desired Future Directions. Looking forward, the USGS has identified several key areas for future research and development in sturgeon culture and propagation, emphasizing the importance of genetic diversity and breeding programs to maintain genetic health and adaptability, which is crucial for the long-term success of propagation efforts. Research will also focus on identifying critical habitat requirements for different life stages of sturgeon and developing effective habitat restoration techniques, linking habitat characteristics with reproductive success to optimize release strategies. Additionally, investigating the prevalence and impact of diseases in cultured sturgeon populations is a priority, with the aim of developing management practices to mitigate these risks in both hatcheries and the wild. Understanding the effects of climate change on sturgeon habitat, migration patterns, and reproductive success is vital for adapting conservation strategies, enabling the development of resilient propagation and management practices that can withstand changing environmental conditions. Finally, the USGS seeks to promote collaboration between government agencies, academic institutions, and fisheries managers to share knowledge, resources, and technologies, thereby enhancing sturgeon conservation efforts and addressing the complex challenges facing sturgeon culture and propagation.

RESEARCH CATEGORY 2: THREATS AND STRESSORS

FOCAL RESEARCH AREA 2A:

COMMERCIAL AND RECREATIONAL HARVEST, CAVIAR INDUSTRY, AND MORTALITY IMPACTS

Introduction: The commercial and recreational harvest of sturgeon and paddlefish, coupled with the caviar industry, has placed significant pressure on these species across North America. Renowned for their valuable roe, sturgeon and paddlefish have historically been subject to overfishing, leading to severe population declines. These pressures are further exacerbated by habitat degradation and other anthropogenic activities that threaten their survival. Effective

regulation and management of these fisheries are essential to ensure the sustainability of these ancient and ecologically significant species. Sustainable harvest practices, habitat restoration, and the mitigation of mortality impacts are critical components of a comprehensive strategy aimed at preserving sturgeon and paddlefish populations for future generations.

USGS Efforts to Date. The USGS has significantly contributed to the understanding and conservation of sturgeon species through various research efforts. For example, studies conducted on the population characteristics of lake sturgeon in Rainy Lake, Minnesota, and Ontario have provided key insights into their migratory patterns and population dynamics, revealing that lake sturgeon in this region are relatively fast-growing and have unique age-structure patterns. Additionally, research on the reproductive biology of pallid sturgeon has employed minimally invasive techniques to estimate gonadosomatic index and fecundity, providing critical data to sustain population numbers (U.S. Geological Survey, 2010). Further studies have assessed the impact of climate change on sturgeon populations, with findings emphasizing the need for habitat restoration and protection, particularly in light of river engineering projects that have disrupted natural habitats (Shaw et al., 2012; Embke et al, 2023). Research on stable isotope analysis has also been utilized to investigate the feeding patterns of juvenile pallid sturgeon, offering valuable data on dietary preferences and habitat use, crucial for targeted conservation efforts.

Desired Future Directions. Future research should prioritize enhanced monitoring and assessment of sturgeon and paddlefish populations using advanced tracking and genetic techniques to gain a comprehensive understanding of population dynamics, which is crucial for informed management decisions and species sustainability. Additionally, it is critical to investigate the effects of commercial and recreational harvesting and incidental catch on population structure, with the aim of developing sustainable harvest strategies that minimize negative impacts, ensuring both the long-term survival of these species and the viability of the caviar industry. Habitat restoration and protection, particularly in areas affected by river engineering and damming, should be implemented and evaluated to support the recovery and sustainability of sturgeon and paddlefish populations. Detailed studies on the potential impacts of climate change on habitats and populations, including alterations in water temperature, flow regimes, and food availability, are necessary to address the challenges posed by climate change to these species' survival and reproductive success. Furthermore, enhancing public awareness

about the importance of sturgeon and paddlefish conservation and supporting the development of policies that promote sustainable fisheries and habitat protection are essential for ensuring that conservation efforts are underpinned by a well-informed public and strong regulatory frameworks.

FOCAL RESEARCH AREA 2B:

EFFECTS OF POLLUTANTS AND CONTAMINANTS

Sturgeon and paddlefish, ancient fish species that have thrived in North American waters for millions of years, are increasingly under threat from pollutants and contaminants. These species, known for their longevity and unique life histories, are exposed to numerous environmental stressors, with pollutants and contaminants being particularly significant. Understanding the effects of these harmful substances on sturgeon and paddlefish is crucial for their conservation and management. Among the most concerning pollutants are endocrine-disrupting chemicals (EDCs), which can interfere with hormonal systems and disrupt normal development. Contaminants, such as heavy metals, organic compounds like PCBs and dioxins, and other environmental toxins are also concerns to early life stages of sturgeon. In addition to direct toxicity, contaminants often impair behavioral responses, such as feeding and swimming, which are critical for survival and long-term fitness.

USGS Efforts to Date. USGS research has focused on understanding the impacts of pollutants and contaminants on sturgeon and paddlefish, particularly during their early life stages. Given the common placement of municipal wastewater treatment plants along rivers in the Northeast, where early life stages of sturgeon are often present, populations may be exposed to wastewater inputs throughout their development. However, there is limited knowledge about how different life stages of sturgeon respond to common environmental endocrine-disrupting chemicals (EDCs) found in wastewater, such as 17B-estradiol (E2), 17 Alpha-ethinylestradiol (EE2), and nonylphenol (NP). In one study, short-term exposure of four early life stages of shortnose sturgeon to environmentally relevant levels of endocrine-disrupting chemicals (EDCs) did not induce an estrogenic response, such as the synthesis of vitellogenin (an egg protein), in either shortnose or Atlantic sturgeon. However, long-term exposure was found to result in reduced

growth. These findings were presented at the 2011 SETAC conference by Tara Duffy and Steve McCormick from the USGS S.O. Conte Anadromous Fish Research Center.

The USGS has conducted extensive research into the impact of industrial pollutants and heavy metals on sturgeon species. For instance, studies on the Columbia River's white sturgeon populations have shown that bioaccumulation of heavy metals, including mercury and lead, poses significant health risks not only to the sturgeon but also to other predators, including humans who consume these fish. Mercury and other contaminants were found in sturgeon tissues, highlighting the environmental persistence of pollutants from industrial activities (Puglis et al., 2020, Payne et al., 2022). Furthermore, research has demonstrated that exposure to pollutants like copper can cause physiological stress and reduced growth rates in juvenile sturgeon. For example, early life stages of white sturgeon exposed to elevated levels of copper exhibited symptoms such as reduced swimming activity and increased mortality, underscoring the risks posed by contaminants in their habitats. These findings are crucial for developing conservation strategies and mitigation efforts, such as habitat restoration and pollution control measures, to protect sturgeon populations and reduce the risks associated with pollutant exposure. Studies on white sturgeon reveal significant vulnerabilities to pollutants such as cadmium, copper, lead, and zinc, particularly during early life stages (Balistrieri et al., 2018). White sturgeon larvae are highly sensitive to copper, with lethal and sublethal concentrations as low as 1.5 µg/L (Little et al., 2014; Wang et al., 2014; Puglis, Farag, and Mebane, 2020). In contrast, Atlantic, lake, shortnose, and shovelnose are relatively less sensitive, ranging from a LC50 of 60 µg/L (Atlantic sturgeon) to 160 µg/L (shovelnose sturgeon), still demonstrate significant sensitivity to environmental relevant concentrations (Dwyer et al. 2005; Besser et al., 2020). Sediment contamination, particularly from smelter slag, poses additional risks through both direct exposure to metals and ingestion of contaminated sediments and prey (Little, Calfee, and Linder, 2014; Puglis, Farag, and Mebane, 2020). Furthermore, the bioavailability of metals from sediments, combined with their impact on benthic prey communities, further limits the recruitment success of sturgeon populations in contaminated areas (Puglis, Farag, and Mebane, 2020; Besser et al., 2018). While dissolved organic carbon (DOC) has been shown to mitigate copper toxicity, it has little effect on zinc toxicity, complicating water quality management in polluted habitats (Ivey et al., 2019). Beyond lethal endpoints, sublethal effects such as behavioral impairments, including reduced swimming and feeding activity, have been observed in white

sturgeon at similarly low concentrations, suggesting that these impacts may be more ecologically significant than previously understood (Calfee et al., 2016; Puglis, Calfee, and Little, 2019). The USGS has conducted extensive research on the toxicity of organic compounds and other environmental contaminants on various sturgeon species, including Atlantic, pallid, shortnose, and shovelnose sturgeon. Studies examining polychlorinated biphenyl (PCB-126) and dioxin (TCDD) in sturgeon eggs revealed that lake sturgeon were the most sensitive to both compounds, with lethal dose (LD50) values of 0.61 ng/g for PCB-126 and 5.4 ng/g for TCDD (Buckler et al., 2015; Tillitt et al., 2017). Pallid and shovelnose sturgeon eggs demonstrated higher tolerance, with LD50 values of 159 ng/g and 196 ng/g for PCB-126 and 12 ng/g and 13 ng/g for TCDD, respectively. Despite this, all species exhibited morphological pathologies such as yolk sac edema, craniofacial deformities, and hemorrhaging (Buckler et al., 2015; Tillitt et al., 2017). Atlantic and shortnose sturgeons were identified as some of the most sensitive species to chemicals such as carbaryl, copper, 4-nonylphenol, pentachlorophenol, and permethrin, ranking 1st and 2nd in sensitivity among other species tested (Dwyer et al., 2005). Permethrin was particularly toxic, causing high mortality in both Atlantic and shortnose sturgeons at low concentrations (Dwyer et al., 2005). Research on ammonia, sulfates, and chlorides has also been conducted on lake and shovelnose sturgeon (Besser et al., 2020), while white sturgeon (A. transmontanus) showed extreme sensitivity to chlorine, with 100% mortality occurring after a 15-minute exposure to 10 mg/L of total residual chlorine (TRC) or a 5-minute exposure to 25 mg/L TRC (Ingersoll et al., 2013).

Desired Future Directions. Moving forward, USGS aims to expand its research on the long-term effects of EDCs and other contaminants on sturgeon and paddlefish, particularly focusing on cumulative and sub-lethal impacts that may not be immediately apparent. This includes further studies on how contaminants affect different life stages and the potential for bioaccumulation in sturgeon and paddlefish tissues. Additionally, there is a need to investigate the broader ecological impacts of pollutants, such as how they affect predator-prey dynamics and overall ecosystem health. Future research will also prioritize the development of more effective monitoring and mitigation strategies to protect these species and the ecosystems they inhabit. This includes collaborating with other agencies and stakeholders to enhance pollutant regulation and develop conservation strategies that account for the impacts of environmental contaminants on sturgeon and paddlefish populations.

FOCAL RESEARCH AREA 2C:

DISEASES AND PATHOGENS

Introduction: Disease significantly impacts the survival and longevity of both wild and propagated sturgeon and paddlefish in North America. While parasitic, bacterial, and fungal infections are present, viruses are the predominant pathogens affecting sturgeon species (Radosavljević et al., 2019; Mugetti et al., 2020). Conversely, parasites are the primary infectious agents in paddlefish (Durborow et al., 2015).

DNA Viruses. Sturgeon Nucleocytoplasmic Large DNA Viruses (sNCLDV) have been linked to numerous disease outbreaks in sturgeon hatcheries across North America and Europe (Hedrick et al., 1990; LaPatra et al., 1994; Raverty et al., 2003; Kurobe et al., 2010, 2011; Ciulli et al., 2016; Bigarre et al., 2017; Axen et al., 2018; Mugetti et al., 2020; Stachnik et al., 2021). Initially classified as iridoviruses, these viruses are now recognized as putative members of the Mimiviridae family (Clouthier et al., 2013, 2018). Frog virus 3 (FV3) from the Iridoviridae family is the only viral pathogen reported to infect and cause disease in sturgeon (Waltzek et al., 2014; Duffus et al., 2015; Stillwell et al., 2022). Additionally, alloherpesviruses like Acipenserid herpesviruses 1, 2, and 3 have been detected in sturgeon with cutaneous lesions and associated mortality events (Hedrick et al., 1991; Watson et al., 1995; Hanson et al., 2016; Johnston et al., 2022; Walker et al., 2022; Clouthier et al., 2023). The white sturgeon adenovirus 1, a non-enveloped dsDNA virus, has been identified in wild and farmed white sturgeon but does not seem to be a major concern for white sturgeon propagation (Hedrick et al., 1985; Doszpoly et al., 2019; Mugetti et al., 2020).

RNA Viruses. Rhabdoviruses, bullet-shaped negative-sense single-stranded RNA viruses, are well-documented pathogens in many fish families but are less common in Acipenseriformes (Durborow et al., 2015; Mugetti et al., 2020). Infectious hematopoietic necrosis virus (IHNV) was detected in asymptomatic paddlefish larvae imported to China, marking the only viral agent associated with paddlefish (Hong et al., 2006). Experimental exposure of white sturgeon to IHNV showed replication in larvae but not in older stages (LaPatra et al., 1995). Pallid sturgeon might be vulnerable to viral hemorrhagic septicemia virus strain IVb (VHSVIVb), though the

level of susceptibility remains unclear (Hopper et al., 2023). Spring viremia of carp virus (SVCV) has been intermittently reported in North America and typically causes disease in cyprinid fish species (Ortega et al., 2019). However, Siberian sturgeon *Acipenser baerii* were reported to be naturally infected and suffered from SVC disease (Vicenova et al. 2011). Aquareoviruses and betanodaviruses have also been reported in sturgeon, with potential impacts on health (Athanassopoulou et al., 2004; Zhang and Gui, 2012; Bandin and Souto, 2020).

Parasites. Parasites are the most common pathogens affecting paddlefish (Durborow et al., 2015). Various species of protists, microsporidians, and metazoans have been documented as parasites of paddlefish (Durborow et al., 2015; Okamura et al., 2020). Sturgeon are also susceptible to numerous parasites, such as Argulus species, Gyrodactylus species, and cnidarians like *Polypodium hydriforme* (Raikova, 2002; Choudhury et al. 2009; Bauman et al., 2011; Munroe et al., 2011; Andres et al., 2019; Okamura et al., 2020; Judd et al., 2022; Leis et al., 2023). Parasite loads can stress paddlefish and sturgeon, and with climate change they may become an increasing pathogenic threat (Haxton 2008; Islam et al. 2022; Timi and Buchmann, 2023(.

Bacteria. Bacterial infections, though common in aquaculture settings, are often opportunistic or secondary to other stressors (Durborow et al., 2015; Radosavljević et al., 2019). Notable bacterial pathogens include *Aeromonas salmonicida*, *Flavobacterium spp*., and *Plesiomonas shigelloides* in paddlefish, and various motile aeromonads in sturgeon (Fujimoto 2012; Fujimoto et al. 2018; Peretta et al., 2018; Santi et al., 2019; Vázquez-Fernández et al., 2023). A direct correlative relationship between infection and morbidity has only been proposed for a few bacterial species. For example, bacteria like *Lactococcus lactis*, *Citrobacter freundii*, and *Vibrio metschnikovii* were linked to mortality in sturgeon (Chen et al., 2012; Yang et al., 2021; Xiao et al., 2022). *Streptococcus iniae* has been repeatedly isolated during sturgeon die-offs, suggesting its role as a primary pathogen (Deng et al., 2015; Muhammad et al., 2020; Pierezan et al., 2020; Colussi et al., 2022; Mugetti et al., 2022). However, it has been more commonly suggested that bacterial infections in sturgeon are typically an opportunistic association or initially subclinical, and only leads to pathogenesis when the fish are in compromised/stressed state (Athanassopoulou et al. 2004, Antuofermo et al. 2014, Soto et al. 2017, Santi et al. 2019, Huang et al. 2020, Chinchilla et al. 2023).

Fungi. Fungal infections may also pose an increasing threat to sturgeon as water temperatures rise due to global warming (Coleman et al., 2018; Bugg et al., 2023). Freshwater molds from the Saprolegniaceae family have compromised sturgeon eggs, and *Veronaea botryosa*, belonging to the Herpotrichiellaceae family, has significantly impacted farmed sturgeon (Czeczuga et al., 1995; Bauer, 2002; Jalilpoor et al., 2006; Fujimoto 2012; Steckler et al., 2014; Groff et al., 2021; Yazdi et al., 2021).

Research to Date. USGS research has been pivotal in identifying and characterizing pathogens that affect sturgeon and paddlefish, with a focus on viral infections that have caused significant mortality in these species. For instance, the study of viral hemorrhagic septicemia virus (VHSV) in pallid sturgeon revealed its ability to replicate in cell lines and cause significant mortality, though the assessment was complicated by co-infections with the Missouri River sturgeon iridovirus (MRSIV) (Hopper et al., 2023). Research on Acipenserid Herpesvirus 3 (AcHV-3) in lake sturgeon has furthered understanding of this virus's impact, leading to the discovery of a new lineage within the Alloherpesviridae family and emphasizing the need for future studies on its pathogenicity (Clouthier et al., 2023). USGS researchers have tested control measures to reduce pathogen loads on sturgeon eggs and participated in microbiota/pathogen assessments of sturgeon species (Chalupnicki et al. 2015: Thurner et al. 2017; Gaughan et al. 2023).

Desired Future Directions. USGS aims to expand research on the interactions between sturgeon and paddlefish with their pathogens, particularly in the context of rising water temperatures, which increase susceptibility to infections. Understanding how thermal stress and co-infections with bacteria, fungi, and viruses affect these species is a critical research priority. Future directions include studying the synergistic effects of multiple pathogens, the development of new diagnostic tools for early detection, and investigating the potential for genetic resistance to infections. Continued research on the impacts of environmental changes on disease dynamics, alongside efforts to develop mitigation strategies, will be essential for the conservation of these species in a changing climate (LaPatra et al., 2014; Soto et al., 2017; Ciulli et al., 2020; Hopper et al., 2023; Zhang et al., 2023).

FOCAL RESEARCH AREA 2D:

INFLUENCE AND IMPACTS OF INVASIVE SPECIES AND CONTROL MEASURES

Introduction: Invasive fish species, particularly bigheaded carps such as Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*Hypophthalmichthys molitrix*), pose significant threats to various life stages of North American Sturgeon and Paddlefish, primarily within the Mississippi River Basin. These invasive species disrupt native ecosystems through direct competition for food, altering food webs, and potentially transmitting diseases. Both paddlefish and bigheaded carps are filter feeders throughout their life stages, which leads to intense competition for food resources. Studies have shown that in the Missouri River, there is a trophic overlap of 26.8% between paddlefish and bighead carp, and 35.4% with silver carp (Wang et al., 2018). In regions like the lower Illinois River, where invasive carps are particularly abundant, the competition for resources severely limits the availability of food for native filter feeders like paddlefish (Harris et al., 2022). Mesocosm studies further demonstrate that Age-0 paddlefish experience significant reductions in growth rates when co-located with bighead carp, highlighting the competitive disadvantage imposed by these invasive species (Schrank et al., 2003). Control methods aimed at managing invasive species, such as physical removals, deterrents, and habitat manipulations, can also impact native species like sturgeon and paddlefish. For example, acoustic deterrents targeting invasive carp have been tested in laboratory settings with paddlefish and lake sturgeon, showing no significant changes in behavior (Murchy et al., 2022). Additionally, in the Great Lakes-St. Lawrence region, efforts to control sea lamprey (*Petromyzon marinus*) overlap with lake sturgeon habitats. Studies on lampricide toxicity have indicated that early life stage lake sturgeon are sensitive to these chemicals, with stream-side toxicity studies showing an 80% survival rate for Age-0 lake sturgeon during lampricide applications (Boogaard et al., 2003; McDonald & Kolar, 2007; O'Connor et al., 2017).

Research to Date. The USGS has undertaken significant research to mitigate the impact of invasive species on native fish populations, focusing on the development and testing of deterrents and control methods that minimize harm to non-target species like sturgeon and paddlefish. For instance, underwater acoustic deterrent systems (uADS) have been assessed at Mississippi River Lock No. 19 to determine their effectiveness in deterring invasive carps while

evaluating potential impacts on native species (Brey et al., 2023). Laboratory trials using boat motor sounds have shown that paddlefish and lake sturgeon do not exhibit significant behavioral changes in response to these deterrents, suggesting that these methods may be selective in targeting invasive species (Murchy et al., 2022). In terms of competition, studies have demonstrated that invasive carps significantly impact the growth of native paddlefish. Mesocosm experiments revealed that age-0 paddlefish exhibit reduced growth when co-located with bighead carp, confirming the competitive pressure imposed by these invasive species (Schrank et al., 2003). The USGS has also explored chemical control measures, including the potential reinstatement of the Antimycin-A liquid formulation, a chemical historically used for native fish restoration projects. Given that paddlefish are particularly sensitive to Antimycin-A, further toxicity studies may be necessary to ensure minimal impact on non-target species (Saari, 2023; Mayer & Ellersieck, 1986). Moreover, the USGS is developing species-specific pesticides and fish gill cytotoxicity assays to predict in vivo toxicity, aiming to enhance the selectivity of chemical controls.

Desired Future Directions. The USGS has identified several key areas for future research to address the ongoing challenges posed by invasive species, with a focus on native species like paddlefish and various sturgeon species, including lake, shovelnose, and pallid sturgeon. Research is needed to understand how modifications in flow regimes at dams, designed to control invasive carp movement, affect the behavior of these native species. Additionally, future studies should explore the effects of selective passageways and invasive carp deterrents on the movement and behavior of North American paddlefish and lake sturgeon, with a priority on developing deterrents that selectively target invasive carps while minimizing impacts on native species. Furthermore, investigating changes in habitat, abundance, and food web dynamics of native sturgeon species, particularly shovelnose sturgeon, in response to increasing populations of invasive carps, is essential for developing effective management and conservation strategies.

FOCAL RESEARCH AREA 2E:

HABITAT DEGRADATION/DREDGING IMPACTS

Introduction: Habitat degradation, particularly due to dredging activities, poses significant threats to aquatic ecosystems and species, including sturgeon. Dredging operations can

dramatically alter riverbeds, disrupt sediment flows, and degrade water quality, all of which negatively impact the essential habitats for the spawning, rearing, and feeding of sturgeon. This physical alteration can directly harm sturgeon through disturbance and indirectly by altering habitat structures and reducing food availability. The preservation of aquatic habitats is crucial for supporting aquatic life in the nation's streams and rivers. Anthropogenic activities such as dredging, loss of riparian buffers, and increased sedimentation influence the fish and macroinvertebrate communities within headwater streams and downstream river ecosystems. These changes can disrupt the natural ecosystem flow, cause instability in fish community functions, and negatively affect species existence and reproduction. In larger aquatic systems, the frequent dredging of major rivers for transportation and shipping routes, such as the Ohio River, further exacerbates these issues. The presence of dams and locks, without proper fish passage alternatives, also acts as barriers to local movement and reproduction, compounding the threats posed by habitat degradation.

USGS Efforts to Date. The USGS has conducted significant research on the impacts of habitat degradation and dredging on sturgeon and other aquatic species. Studies have found that dredging activities alter sediment composition and disrupt sturgeon spawning habitats, which can negatively affect reproductive success. For example, research on the Lower Missouri River documented changes in sediment dynamics and habitat conditions, emphasizing the importance of sediment stability for successful sturgeon reproduction (Elliott, DeLonay, & Chojnacki, 2020). Additionally, USGS studies highlighted that habitat degradation, such as changes in water quality and sedimentation, impacts the feeding patterns of sturgeon. The alteration of benthic habitats reduces the availability of key prey species, further compromising sturgeon populations' ability to thrive (DeLonay et al., 2019). Long-term monitoring has revealed that habitat fragmentation due to dredging activities can also increase sturgeon mortality rates by disrupting migratory pathways and essential feeding grounds. These insights have been crucial in formulating habitat restoration and management strategies, with USGS contributing valuable data on the relationship between habitat quality and sturgeon population dynamics in large river systems like the Missouri and Mississippi rivers. These efforts extend beyond sturgeon, benefiting broader aquatic ecosystem management, including invasive species assessments and conservation efforts in major tributaries like the Ohio River.

Desired Future Directions. To further advance the understanding and mitigation of habitat degradation impacts, the USGS has identified several key areas for future research. These include continued long-term monitoring of sturgeon populations and habitats to assess the cumulative impacts of dredging over extended periods, providing critical data for understanding trends and informing management decisions. Research should also focus on developing and evaluating effective dredging mitigation strategies that minimize habitat disruption, such as investigating alternative dredging techniques, optimizing the timing of activities to avoid sensitive periods, and implementing post-dredging habitat restoration efforts. Enhancing hydrodynamic models to predict the impacts of dredging on sediment transport and habitat structure is crucial, as these models can assist in planning operations that reduce negative impacts on critical habitats. Collaboration between hydrologists, ecologists, and fisheries biologists is necessary to develop comprehensive management plans addressing the ecological, physical, and biological aspects of habitat degradation. Additionally, increased efforts are needed to translate scientific findings into public policy and raise public awareness about the impacts of dredging, advocating for stronger regulations and enforcement to protect sturgeon habitats and ensure the long-term conservation of these species.

CASE EXAMPLE

International Partnerships for Lake Sturgeon. The USGS Great Lakes Science Center (Ann Arbor, MI) has been a leading partner in an international partnership to restore lake sturgeon spawning habitat and evaluate the effectiveness of restoration in the St. Clair-Detroit River System. This partnership lead to the development of long-term spawning surveys in the system, methods for effectively monitoring the early life history stages of lake sturgeon in this critical international shipping corridor. USGS engages partners, outside entities, and the public across the Great Lakes basin regarding the process evolution used for spawning habitat restoration, as well as the techniques for monitoring, through presentations and outreach events. This regional partnership continues almost 20 years later with assessments of spawning reef maturation, spawning and non-spawning adult and early life stage use, adult movements in the system, and assessments of genetic implications for the addition of spawning reefs in the system.

FOCAL RESEARCH AREA 2F:

WATER FLOWS, QUALITY, AND AVAILABILITY IMPACTS

Introduction: Water flows, quality, and availability are critical factors that shape aquatic ecosystems, particularly for species like sturgeon that rely on specific habitat conditions for survival and reproduction. Changes in water flow patterns, deterioration in water quality, and fluctuations in water availability can have profound effects on sturgeon populations. These factors influence the availability of suitable spawning and feeding grounds, impact the health and survival of sturgeon, and affect their ability to access critical habitats. Altered river flows, exacerbated by climate change, can disrupt migration patterns, while poor water quality, including temperature fluctuations, low dissolved oxygen levels, and the presence of contaminants, can reduce sturgeon survival rates and impair reproductive success. Moreover, during drought conditions, reduced water levels can lead to habitat fragmentation, limiting sturgeon access to vital spawning sites. The cumulative impacts of water regulation and land use changes, driven by anthropogenic activities, have significantly altered water flow regimes, leading to habitat degradation and increased mortality rates among sturgeon populations.

USGS Efforts to Date. The USGS has extensively researched the effects of water flows, quality, and availability on sturgeon populations, contributing to our understanding of how these factors affect sturgeon habitats, health, and survival. Studies have shown that altered river flows, often due to human activities such as damming and water regulation, significantly disrupt sturgeon migration patterns and reduce the availability of suitable spawning and feeding habitats (DeLonay et al., 2009; USGS, 2010). For example, water quality issues such as elevated temperatures, low dissolved oxygen levels, and the presence of contaminants have been linked to impaired health and reduced reproductive success in sturgeon species, emphasizing the need for maintaining healthy aquatic environments. Additionally, research has highlighted the consequences of drought and reduced water availability on sturgeon populations. During drought conditions, sturgeon habitats can become fragmented, limiting their access to critical spawning grounds, which can drastically reduce population recruitment and survival rates (Embke, Nikiel, & Lyons, 2023). USGS studies have also examined the cumulative impacts of water regulation and land use changes, showing that altered flow regimes lead to habitat degradation and increased mortality among sturgeon populations (Embke, Nikiel, & Lyons, 2023). Moreover, the USGS has explored the potential effects of climate change, predicting that warming temperatures and altered precipitation patterns could further reduce habitat availability and spawning success for species like lake sturgeon (Sullivan et al., 2003). USGS's continuous monitoring through

streamgages and real-time water quality assessments, especially in major rivers such as the Ohio River, has provided crucial data on parameters like temperature, dissolved oxygen, and sediment levels, which are essential for sturgeon conservation efforts (Embke, Nikiel, & Lyons, 2023). This research supports a comprehensive understanding of how water flow, quality, and availability play critical roles in the survival and recovery of sturgeon populations across various aquatic systems.

Desired Future Directions. To address remaining gaps and enhance conservation efforts, the USGS has outlined several desired future research directions, including the development of integrated hydrological and ecological models that predict the effects of various water management scenarios on sturgeon habitats and populations, providing essential tools for conservation planning. Establishing and expanding long-term monitoring programs to track changes in water quality and availability, and their impacts on sturgeon populations over time, is crucial for understanding long-term trends and informing adaptive management strategies. Additionally, investigating the potential impacts of climate change on water flows, quality, and availability, and how these changes will affect sturgeon populations, particularly in the context of increased frequency and severity of droughts and floods, is a critical research need. The USGS also emphasizes the importance of designing and testing restoration and mitigation strategies to improve water quality and availability for sturgeon habitats, which could involve habitat restoration projects, improved water flow management practices, and pollution control measures.

RESEARCH CATEGORY 3: POPULATION RESEARCH, MONITORING, AND MANAGEMENT EFFORTS

FOCAL RESEARCH AREA 3A:

SENSITIVE SPECIES ADAPTIVE MANAGEMENT, DECISION SUPPORT, AND RECOVERY PLANNING

Introduction: The USGS is active in and play vital roles in various adaptive management, decision support, and recovery planning efforts and initiatives. These efforts are mostly centered

on developing innovative monitoring tools, refining population indices, conducting population viability analyses, and executing comprehensive stock assessments.

USGS Efforts to Date. The USGS has made significant strides in sturgeon and paddlefish conservation through various research initiatives. For example, the Value of Information (VOI) framework, integrated with sturgeon management objectives, plays a crucial role in the Central Valley Project Improvement Act (CVPIA) and the Central Valley Project Improvement System Decision Management and Adaptive Resource Management (CVPI SDM/ARM) initiatives, aimed at sustaining sturgeon populations in the Central Valley and beyond. For pallid sturgeon, particularly within the Missouri River ecosystem, adaptive management is a central focus, with efforts tailored to the species' unique challenges to support its recovery. Similarly, paddlefish conservation is guided by strategic decision-making and adaptive management, emphasizing the development of sustainable management practices. The USGS has also advanced Atlantic sturgeon research by developing models that combine acoustic telemetry and side-scan sonar to estimate spawning run sizes in large river systems, as well as applying pedigree-reconstruction techniques to estimate successful spawner numbers in the Hudson River. The agency actively contributes to regional conservation through its involvement in the Atlantic States Marine Fisheries Commission's Atlantic Sturgeon Technical Committee and Stock Assessment Subcommittee and engages in recovery planning for various Distinct Population Segments of Atlantic sturgeon. Additionally, the USGS provides expert insights at US Army Corps of Engineers workshops, particularly concerning the impacts of dredging on sturgeon populations.

Desired Future Directions. Looking forward, the USGS aims to develop more cost-effective monitoring tools that can be easily transferred to partners, ensuring sustainable, long-term monitoring of sturgeon and paddlefish populations. This includes refining existing technologies and methodologies to reduce costs while maintaining accuracy and reliability. By focusing on the creation of accessible and affordable monitoring tools, the USGS seeks to enhance the capacity of its partners to contribute to the ongoing conservation and recovery efforts, ultimately leading to more resilient sturgeon and paddlefish populations across North America.

FOCAL RESEARCH AREA 3B:

SENSITIVE SPECIES MONITORING

Introduction: Sensitive species monitoring is essential for understanding the health, viability, and long-term sustainability of species populations, particularly those that are threatened or endangered. This monitoring plays a crucial role in informing conservation efforts, mitigating human impacts, and ensuring the stability of ecosystems. Among the species that require detailed monitoring are sturgeon species, such as the lake sturgeon (*Acipenser fulvescens*) and green sturgeon (*Acipenser medirostris*), which are both experiencing declining populations and hold significant ecological importance. Monitoring efforts for these species are vital in tracking population trends, identifying critical habitats, and assessing the effectiveness of conservation measures aimed at their recovery.

USGS Efforts to Date. The USGS has conducted comprehensive research on sturgeon species, contributing valuable insights into their population dynamics, habitat use, and responses to environmental changes. Studies on lake sturgeon movements in Rainy Lake, Minnesota, and Ontario have provided critical data on their spatial ecology and migratory patterns, essential for informed conservation strategies (Adams Jr., Kallemeyn, & Willis, 2006). Further research has focused on green sturgeon, assessing population status and identifying conservation needs to mitigate threats such as habitat degradation and overfishing (Adams et al., 2007). In addition, USGS developed non-invasive techniques to estimate the gonadosomatic index and fecundity of the endangered pallid sturgeon in the Lower Missouri and Middle Mississippi Rivers, offering a significant advancement in reproductive health assessments, which are crucial for conservation planning. Studies of the Atlantic sturgeon in the Hudson River estuary also provided valuable data on harvest impacts and habitat requirements, guiding habitat protection and management efforts (Bain et al., 2000).

Desired Future Directions. To build on the progress made so far, the USGS has identified several key areas for future research and monitoring efforts, including the need for long-term longitudinal studies to monitor population trends over extended periods, providing a clearer understanding of conservation effectiveness and allowing for timely adjustments to management strategies. Genetic studies are also crucial for investigating the diversity within and between sturgeon populations, which will inform breeding and reintroduction programs and help maintain the health and resilience of sturgeon in the face of environmental changes and anthropogenic pressures. Additionally, habitat restoration efforts will focus on identifying and prioritizing critical habitats essential for different life stages of sturgeon, ensuring these areas support

survival and reproduction. Finally, assessing the impacts of climate change on sturgeon habitats and populations is essential for developing adaptive management strategies, as changes in water temperatures, flow regimes, and habitat availability pose significant challenges to the long-term sustainability of these species.

FOCAL RESEARCH AREA 3C:

RESEARCH FUNDING AND RESOURCES

Introduction: Securing adequate funding and resources is crucial for the ongoing and future research efforts aimed at conserving sensitive species like sturgeon. This encompasses not only the acquisition of financial support but also ensuring the availability of technological tools and human expertise necessary for conducting comprehensive research. Without sufficient funding and resources, the ability to carry out essential research, implement conservation strategies, and adapt to new challenges is significantly hindered. Therefore, a robust strategy to secure and allocate resources effectively is a cornerstone of successful conservation efforts.

USGS Efforts to Date. The USGS has made significant strides in sturgeon conservation research, supported by the effective use of existing resources and collaborative efforts. For instance, the application of stable isotope analysis to assess the feeding patterns of juvenile pallid sturgeon was made possible through collaborative research efforts (Andvik et al., 2010). Additionally, the implementation of zero-inflated modeling of fish catch data has greatly improved the understanding of sturgeon populations, showcasing the effective use of advanced statistical methods in research (Arab et al., 2008). These examples highlight the importance of both financial support and the availability of specialized tools and expertise in achieving research milestones.

Desired Future Directions. To build on past successes, the USGS emphasizes several key areas for future focus, including increased resources from federal, state, and private sources to sustain long-term studies, implement large-scale projects, and ensure the continuation of critical research initiatives. Collaborative partnerships with academic institutions, non-profit organizations, and international bodies are also prioritized to leverage additional expertise and resources, thereby enhancing the scope and impact of research efforts. Additionally, the integration of cutting-edge technologies such as environmental DNA and remote sensing is

crucial for improving the accuracy and efficiency of sturgeon research. Furthermore, the USGS plans to enhance training and development opportunities for researchers and conservationists to build a skilled and knowledgeable workforce dedicated to sturgeon conservation, ensuring the sustainability of these efforts in addressing current and future challenges.

SECTION 4: Data and Information Needs for Sturgeon and Paddlefish Research

The conservation and management of sturgeon and paddlefish rely on comprehensive, high-quality data to guide effective decision-making and ensure the sustainability of these ancient species. The USGS recognizes the urgent need for a more integrated approach to data collection, stewardship, and sharing. To address this need, the USGS proposes establishing a *National Sturgeon and Paddlefish Data and Research Information Network* that will enhance data management, facilitate information exchange, and foster collaboration across various stakeholders, including federal and state agencies, tribal organizations, NGOs, academic institutions, and international partners. To date, the USGS has made significant progress in the collection and management of sturgeon and paddlefish data through various partnerships and initiatives. Collaborations with federal and state agencies, tribal organizations, NGOs, and academic institutions have yielded extensive datasets on the life history, population dynamics, habitat use, and health of these species. For example, efforts to compile population dynamics data have been instrumental in understanding the status and trends of sturgeon and paddlefish across different regions (RL&L Environmental Services Ltd., 2000). However, despite these efforts, significant data gaps remain, particularly in areas such as reproductive biology, genetic diversity, and the impacts of environmental stressors. The USGS recognizes the need for a more integrated approach that includes a centralized database to consolidate data from various sources, making it more accessible and useful for decision-makers. Standardizing data collection and reporting protocols is another critical goal to ensure that information from different studies and regions can be effectively compared and utilized (DeVore et al., 1999; Duke et al., 2004).

Example Goals and Objectives of a National Sturgeon and Paddlefish Data Network:

- *Data Integration*: A key objective would be to consolidate existing data from multiple sources into a centralized, accessible database. This could include information on population dynamics, habitat use, genetics, health, disease, and environmental conditions, ensuring that management decisions are informed by the most comprehensive and current data available.
- *Standardization:* To improve the comparability of research findings, a shared network could develop standardized protocols for data collection, analysis, and reporting. Standardization is crucial to ensure consistency across studies and regions, thereby enabling science-based conservation and management strategies.
- *Collaboration:* The network could foster collaboration among researchers, managers, rightsholders, and other stakeholders. By sharing knowledge, resources, and best practices, it would leverage collective expertise and ensure that conservation efforts are well-informed and widely supported.
- *Decision Support:* The network would provide tools and resources such as predictive models, risk assessments, and monitoring frameworks to support management and conservation strategies. These tools would help guide decisions related to habitat protection, population management, and environmental stressor mitigation.
- *Public Engagement:* Engaging the public through outreach, education, and citizen science programs could be a core component of the network. This would help raise awareness, enhance public participation in conservation efforts, and incorporate indigenous knowledge and other local insights into the decision-making process.

Examples of Identified Data and Information Gaps/Needs:

- *Population Dynamics and Trends:* Comprehensive, long-term data on population sizes, age structures, and reproductive rates are essential for assessing population health and viability. This information is not available for many populations, and generating this data, in addition to sharing it across agencies, is a critical role for the USGS.
- *Habitat Use and Availability*: Comprehensive mapping of critical habitats, including spawning, nursery, feeding, and migratory corridors, is necessary. Collaborative efforts in

habitat mapping and data sharing will guide habitat protection and restoration initiatives more effectively.

- *Genetic Diversity and Population Structure*: Genetic studies are crucial for understanding population structure, genetic diversity, and connectivity among populations. Coordinated genetic research and data sharing can help identify distinct population segments for protection and design effective breeding programs.
- *Impact of Environmental Stressors*: Research on the impacts of pollutants, habitat degradation, climate change, and other environmental stressors on sturgeon and paddlefish health is needed. Sharing these findings can inform mitigation strategies and adaptive management plans across different regions and agencies.
- *Behavioral and Ecological Studies:* Detailed studies on the behavior and ecology of sturgeon and paddlefish, including migration, feeding, and spawning behaviors, are necessary. Coordinated ecological studies will enhance understanding of these species' life cycles and interactions with their environments.
- *Technological Advancements*: Advances in technologies such as telemetry, environmental DNA (eDNA), and remote sensing offer opportunities to improve data collection efficiency and accuracy. Shared use and integration of these technologies across agencies can enhance real-time monitoring and provide a comprehensive understanding of sturgeon and paddlefish populations and habitats.

Addressing data and information needs through coordinated efforts provides numerous benefits. High-quality, shared data enables scientists, resource managers, and policymakers to make informed, science-based decisions, ensuring the effectiveness of conservation strategies. Coordination also prevents the duplication of efforts, allowing for more efficient use of limited resources as agencies pool their expertise to achieve common goals. By sharing data across agencies, a holistic understanding of sturgeon and paddlefish populations and their habitats is gained, which is crucial for addressing complex, multi-jurisdictional conservation challenges. Adaptive management, essential in the face of climate change, becomes possible through shared data that allows continuous evaluation and adjustment of strategies. Moreover, collaboration among federal, state, tribal, local agencies, NGOs, and academic institutions is enhanced, integrating conservation efforts to tackle the complex issues facing these species. Finally,

coordinated, immediate action is critical to preventing further declines in critically endangered or threatened sturgeon and paddlefish species, ultimately working towards their recovery.

SECTION 5: REFERENCES AND APPENDICES

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APPENDICES

Appendix A. Compilation of USGS Sturgeon and Paddlefish Research Products to Date

Appendix B. USGS Centers, Scientists, and Programs Conducting Sturgeon and Paddlefish Research