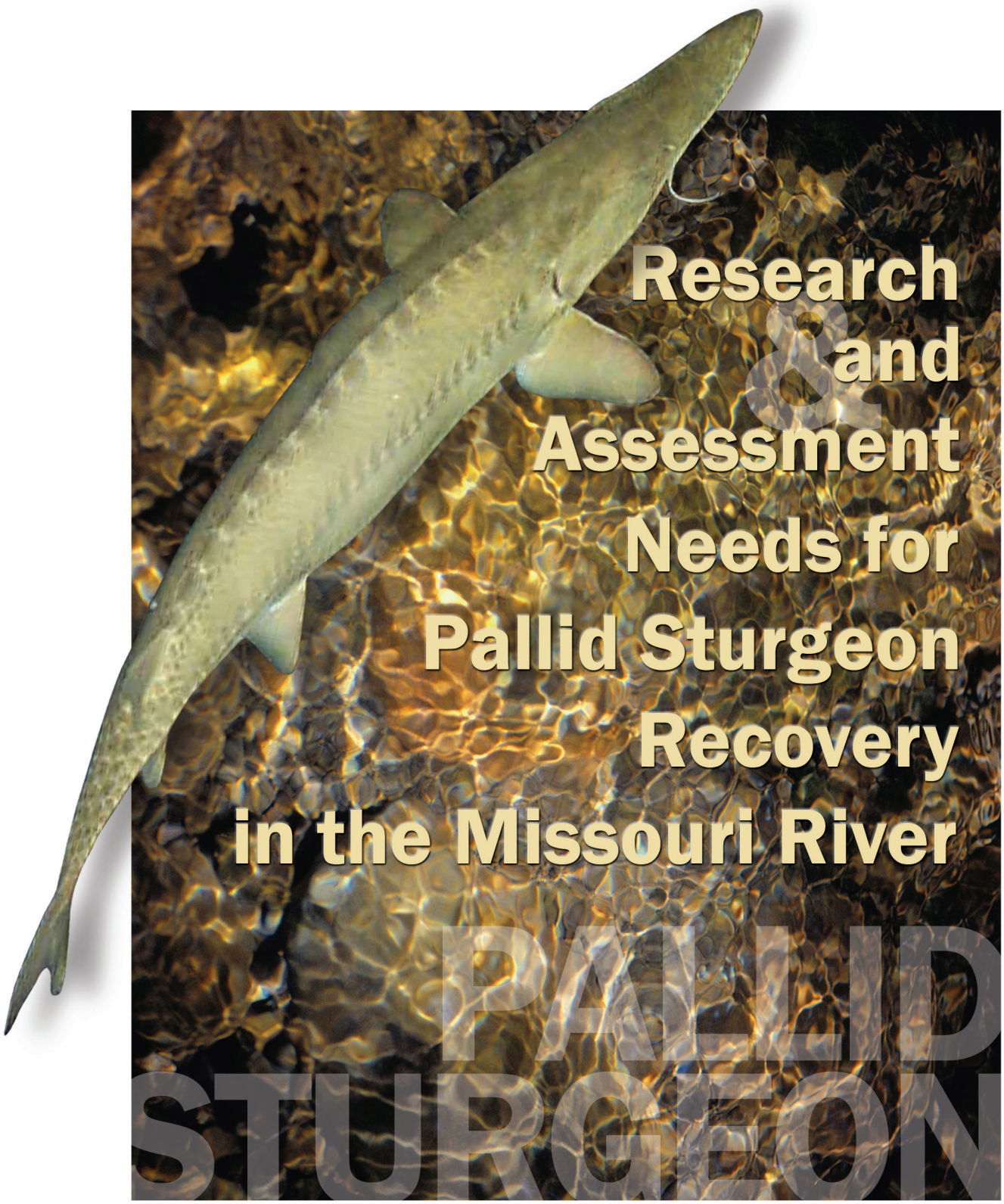


PROCEEDINGS OF A CONFERENCE HELD ON MAY 18-20, 2004 • BLOOMINGTON, MN

Final Report to the U.S. Geological Survey, U.S. Army Corps of Engineers,
U.S. Fish and Wildlife Service, and U.S. Environmental Protection Agency

November 2004

This report may be cited:

Quist, M.C., A.M. Boelter, J.M. Lovato, N.M. Korfanta, H.L. Bergman, D.C. Latka, C. Korschgen, D.L. Galat, S. Krentz, M. Oetker, M. Olson, C.M. Scott, and J. Berkley. 2004. *Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River.* Final report to the U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and U.S. Environmental Protection Agency. William D. Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie.

To obtain a copy of this report contact Julia Towns, Librarian, U.S. Geological Survey, Columbia Environmental Research Center, 4200 New Haven Road, Columbia, MO 65201. Phone 573.876.1853. Email jtowns@usgs.gov.

Electronic copies of this report are available online from the Missouri River Infolink website: http://infolink.cr.usgs.gov/Science/PallidSturgeon/PSWorkshop04.pdf

Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River

Proceedings of a Conference held on May 18-20, 2004 Bloomington, MN

Report to the U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and U.S. Environmental Protection Agency

Prepared by:

Michael C. Quist
Wyoming Cooperative Fish and Wildlife Research Unit
University of Wyoming

Ann M. Boelter, Jill M. Lovato, Nicole M. Korfanta, and Harold L. Bergman
William D. Ruckelshaus Institute of Environment and Natural Resources
University of Wyoming

In cooperation with the

Pallid Sturgeon Research Workshop Steering Committee:

Carl Korschgen and David L. Galat
U.S. Geological Survey

Doug C. Latka
U.S. Army Corps of Engineers

Steven Krentz, Michael Oetker, Michael Olson, and Charles M. Scott
U.S. Fish and Wildlife Service

Jim Berkley
U.S. Environmental Protection Agency

November, 2004

Table of Contents

Tables and Figures

Appendices

Foreword

The subject of this workshop is an excellent example of a type of environmental challenge we face around the world. Many decisions about management of important natural resources must be made in an atmosphere of high uncertainty and high stakes. Pallid sturgeon in the Missouri River basin are threatened with extirpation due to many factors. Those cited most often include habitat degradation and habitat loss, changes in hydrology and in water quality as a result of human activities such as dam operation and river channelization. How do we reverse that threat? Can we reverse the threat while preserving benefits society derives from managing the river for commercial purposes? Effective management of ecosystems is at the heart of finding solutions to such problems, but effective management requires more scientific understanding than we typically have at hand.

The Pallid Sturgeon Research Workshop was an important step toward some answers to these questions. Experience in other situations (e.g., the CALFED Bay-Delta Program in California) shows the value of open discussions that identify technical issues, clarify the state of knowledge, and provide direction about what needs to be learned. Scientific workshops happen all the time but most have little direct impact on management and policy. This pallid sturgeon workshop holds promise for shaping policy and management, and the ingredients of the workshop suggest broad lessons about how science can constructively contribute to policy solutions.

Simple solutions were not evident. The workshop happened at a time when few were satisfied with the state of the policy and management debate. In light of the complexity of the issues, the time seemed right to bring a breadth of scientific expertise to the table.

Participants. Just because several agencies and stakeholders are involved in an issue does not mean they have a common view of the technical problems. Affected agencies worked together to identify key issues and posed several questions for consideration at the workshop. Agency experts participated in, but did not dominate, the technical discussions.

Outside experts. Pallid sturgeon experts from the Missouri River basin worked with sturgeon experts from outside the basin to characterize the state of knowledge, identify uncertainties, and identify the greatest needs for new knowledge. The outside expertise added a new element of creativity and credibility to the discussions.

Uncertainty. Participants agreed that one major goal was to identify and characterize uncertainties about the status of the problem and how to manage it, rather than arguing about values (what the policy should be) or whose interpretation of existing conditions was correct. On the other hand, it was recognized that policy and management will move forward, whatever the state of knowledge. The dialogue was constructive, future oriented, and focused on the link between knowledge and what to do next in terms of both science and policy.

Transparency. It was critical that the workshop was open to all interested parties. At times, the science discussion was messy but it was obvious that those involved were serious about finding constructive solutions for the species.

Iteration. It was recognized that repeated multi-party science forums are an essential part of future management, with review and participation by outside experts. Managing adaptively is clearly essential and repeated discussion of technical issues is the critical ingredient in feeding back new knowledge to policy and management.

Effectiveness. Participants generally felt that this format was an effective way of fostering an exchange of ideas that will contribute to improved recovery efforts for the species.

The research needs laid out by the workshop participants will help guide a productive path forward, whatever the future policy decisions. The constructive dialogue, scientific discourse, and widespread feeling of common ownership that resulted may be as valuable as the material accomplishments.

Samuel N. Luoma
U. S. Geological Survey
Menlo Park, CA

Workshop Participants, Steering Committee, and Observers

Alan Allert
U.S. Geological Survey
Columbia, MO

Nancy Auer
Michigan Technol. Univ.
Houghton, MI

^Bob Bacon
Missouri Dept. Nat. Res.
Jefferson City, MO

^Bill Beacom
Nav-Con Services
Sioux City, IA

*Jim Berkley
U.S. Environ. Prot. Agency
Denver, CO

Pat Braaten
U.S. Geological Survey
Ft. Peck, MT

^Sue Camp
U.S. Bur. of Reclamation
Billings, MT

Doug Carlson
NY Dept. Environ. Conserv.
Watertown, NY

Joyce Collins
U.S. Fish & Wildlife Service
Marion, IL

Roger Collins
U.S. Fish & Wildlife Service
Bismarck, ND

Tommy Crawford
Missouri Dept. Conservation
Warsaw, MO

Jan Dean
U.S. Fish & Wildlife Service
Natchitoches, LA

Mark Drobish
U.S. Army Corps of Engin.
Yankton, SD

Grant Feist
Oregon State University
Corvallis, OR

*David Galat
USGS/Univ. of Missouri
Columbia, MO

Bill Gardner
MT Fish, Wildlife & Parks
Lewistown, MT

Joanne Grady
U.S. Fish & Wildlife Service
Columbia, MO

Chris Guy
Montana State University
Bozeman, MT

Ed Heist
Southern Illinois University
Carbondale, IL

^Mary Henry
U.S. Fish & Wildlife Service
Denver, CO

Dave Herzog
MO Dept. of Conservation
Jackson, MO

Rob Holm
U.S. Fish & Wildlife Service
Riverdale, ND

^Harold Hommes
IA Dept. Ag. Land Stew.
Des Moines, IA

Robb Jacobson
U.S. Geological Survey
Columbia, MO

^Don Jorgensen
Lakota Consulting
Jefferson, SD

Jack Killgore
U.S. Army Corps of Engin.
Vicksburg, MS

*Carl Korschgen
U.S. Geological Survey
Columbia, MO

*Steven Krentz
U.S. Fish & Wildlife Service
Bismarck, ND

Bernie Kuhajda
University of Alabama
Tuscaloosa, AL

Boyd Kynard
U.S. Geological Survey
Turner Falls, MA

*Doug Latka
U.S. Army Corps of Engin.
Omaha, NE

Steve Lydick
U.S. Fish & Wildlife Service
Grand Island, NE

Samuel N. Luoma
U.S. Geological Survey
Menlo Park, CA

^Michael Mac
U.S. Geological Survey
Columbia, MO

Gerald Mestl
Nebraska Game & Parks
Lincoln, NE

Jim Michaels
Florida Mote Marine Lab
Sarasota, FL

*Michael Oetker
U.S. Fish & Wildlife Service
Fort Snelling, MN

*Michael Olson
U.S. Fish & Wildlife Service
Bismarck, ND

^Richard Opper
Missouri River Basin Assoc.
Lewistown, MT

Diana Papoulias
U.S. Geological Survey
Columbia, MO

Vaughn Paragamian
Idaho Fish & Game
Coeur d'Alene, ID

James Parham
University of Nebraska
Lincoln, NE

Mike Parsley
U.S. Geological Survey
Cook, WA

Ed Peters
University of Nebraska
Lincoln, NE

Bobby Reed
LA Dept. Wildl. & Fish.
Lake Charles, LA

*Charles Scott
U.S. Fish & Wildlife Service
Columbia, MO

Wayne Stancill
U.S. Fish & Wildlife Service
Pierre, SD

^Nick Stas
Western Area Power Admin.
Billings, MT

Bill Wayman
U.S. Fish & Wildlife Service
Warm Springs, GA

Molly Webb
University of Oregon
Corvallis, OR

Mark Wildhaber
U.S. Geological Survey
Columbia, MO

^Cindy Williams
U.S. Bur. of Reclamation
Billings, MT

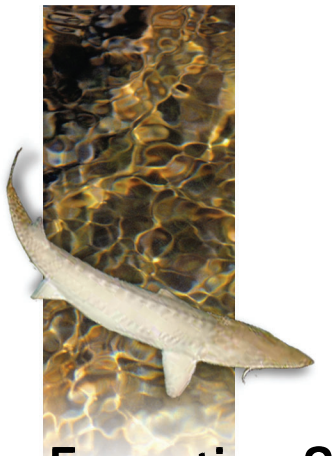
Rob Wood
Saint Louis University
St. Louis, MO

^Charles Wooley
U.S. Fish & Wildlife Service
Fort Snelling, MN

---

*Steering Committee

^Observer



Executive Summary

The U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and U. S. Environmental Protection Agency sponsored a workshop on May 18-20, 2004 in Bloomington, MN, to identify research needed to reduce uncertainty related to pallid sturgeon (*Scaphirhynchus albus*) recovery efforts in the Missouri River system. At the request of these agencies, the University of Wyoming's William D. Ruckelshaus Institute of Environment and Natural Resources organized and facilitated the workshop and prepared this report. The Institute provides independent, third-party support for collaborative approaches to addressing science and policy issues. Results of the workshop will help managers develop a research program to identify critical factors influencing pallid sturgeon and how those factors are affected by river operations and management.

Thirty-six invited technical experts from state and federal agencies, universities, and private organizations plus Steering Committee members and observers identified a multitude of critical research needs necessary for reducing uncertainty in pallid sturgeon recovery efforts. Given the current status of pallid sturgeon, all of the research needs identified by workshop participants are considered important. Highest priority research needs were identified based on presentations each breakout group made during plenary sessions and on a thorough review of all discussions held during the workshop. Highest priority research needs included:

- Reproduction and spawning—Identify environmental cues and factors related to gamete maturation, spawning movements, and egg deposition.
- Early life history stages—Identify factors associated with (1) egg survival, (2) habitat use, availability, and selection by larvae and juveniles, (3) prey use, availability, and selection by larvae and juveniles, and (4) the influence of predation and other species interactions on eggs, larvae, and juveniles.
- Hybridization and genetics—Evaluate occurrence and extent of hybridization between shovelnose sturgeon (*S. platorhynchus*) and pallid sturgeon and determine the genetic structure of wild and broodstock populations.

- Population assessment and monitoring—Develop and implement standardized sampling methodologies and experimental designs for monitoring pallid sturgeon populations.
- Population augmentation—Evaluate and enhance techniques to maximize survival and health of broodstock including developing a diet that provides for healthy growth.
- Fish health—Develop sensitive and accurate diagnostic tools for detecting iridovirus and health baselines (e.g., blood chemistry) for pallid sturgeon.
- Habitat and flow—Develop a classification system for quantifying and monitoring habitat characteristics and identify the dominant processes (e.g., flow, sediment transport) that create and maintain vitally important habitat for pallid sturgeon in the Missouri River and its tributaries.

Workshop participants were also asked to identify short-term research needs and considerations related to flow and habitat manipulations, and those related to high priority research topics. Workshop participants suggested that the design of flow experiments should include temperature and sediment considerations instead of simply a calendar date. Experimental flows also should consider magnitude and duration of flow in addition to timing.

Workshop participants suggested that the entire fish assemblage should be monitored along with pallid sturgeon to evaluate construction of shallow-water habitats in the lower Missouri River. In addition, laboratory studies could be used to determine habitat selection by larval pallid sturgeon and would aid in the design of constructed habitats.

Short-term opportunities related to other research topics were similar to the high-priority research needs and focused on developing diagnostic tools for iridovirus and fish health, identifying the occurrence and frequency of hybridization, identifying food habits and habitat use of larvae and juveniles (in the field and laboratory), developing standardized sampling protocols, and synthesizing current information on pallid sturgeon ecology to further refine research needs and hypotheses.

After the technical portion of the workshop, a public information exchange was held to inform stakeholders about the workshop and to hear their ideas and concerns. Key contributions of the observers through the course of these discussions were to highlight the importance of tributaries and predation. All stakeholders agreed that the process of the workshop was open and transparent and that frequent communication and collaboration between agencies and stakeholder groups will be necessary into the future.

This workshop was an important step in the process aimed at recovering pallid sturgeon in the Missouri River basin. The workshop was significant because it brought together agency representatives and other technical experts to collaboratively discuss critical research needs. Furthermore, this effort took place in an open forum with public observers who contributed to the discussions. It was one of the few occasions when

pallid sturgeon experts and managers in the Missouri River basin have met together with other sturgeon experts from outside the basin. Through these discussions an extensive set of research needs was identified. The next step is to maintain momentum and build upon this progress to implement research to address these critical research needs. Based on presentations and discussions at the workshop and among Steering Committee members following the workshop, the authors of this report recommend the following next steps:

1. Collaborate among agencies and stakeholders on prioritizing these research needs, particularly in the context of information needs associated with the planned flow release experiments in 2006 and current construction of shallow-water habitats in the lower Missouri River.

2. Develop guidelines on how research will be conducted and the process for agency and stakeholder cooperation and participation in guiding research activities.

3. Incorporate independent science review in research, propagation, monitoring, and management activities.

4. Establish a mechanism for continued stakeholder involvement and information exchange. The Missouri River Recovery Implementation Committee (MRRIC) was proposed in the Master Manual (Final 2004 Master Water Control Manual, U.S. Army Corps of Engineers) and is one approach for stakeholder involvement.

5. Establish a mechanism for coordination, data management, and information exchange among scientists and managers conducting research, propagation, and monitoring of *Scaphirhynchus* sturgeons and implementing and evaluating mitigation in the Missouri River system.

These steps should be implemented within an adaptive management framework, allowing managers and researchers to adjust priorities if needed as new information becomes available and to incorporate new information into river management programs.

Research and assessment needs outlined herein are intended to complement, not supersede or replace, previous efforts at identifying actions for pallid sturgeon recovery.

Introduction

The pallid sturgeon (*Scaphirhynchus albus*) is a benthic fish adapted to large, turbid, free-flowing rivers and is considered endemic to the Yellowstone River, Missouri River, middle and lower Mississippi River, and the lower segments of their major tributaries (Bailey and Cross 1954). Although never common, pallid sturgeon populations have experienced significant declines in distribution and abundance. The pallid sturgeon was listed as an endangered species under the Endangered Species Act in 1990 (55 FR 36641-36647). Primary reasons for listing included extensive habitat modification, an apparent lack of reproduction and recruitment, and continued threats from commercial harvest and hybridization in portions of their distribution. Recent research has greatly expanded knowledge on pallid sturgeon ecology, but many uncertainties continue to hinder recovery efforts.

Recent actions by the U.S. Fish and Wildlife Service (USFWS) and the U.S. Army Corps of Engineers (USACE) have resulted in a coordinated effort to promote research on pallid sturgeon in the Missouri River basin. The broad objective of this research is to understand the critical ecological factors that influence pallid sturgeon in the Missouri River and how these factors are affected by river operations and management. The collaborating federal agencies (USFWS, USACE, U.S. Geological Survey [USGS], and U.S. Environmental Protection Agency [USEPA]) are committed to implementing a process that establishes research priorities for pallid sturgeon within an adaptive management framework aimed at reducing uncertainty surrounding pallid sturgeon ecology and management. It is important to note that while uncertainties exist, attempts to implement recovery actions will proceed based on the best available information and professional judgment, pending more definitive results from research, monitoring, and assessment. To aid in developing this process, a workshop was organized to identify the primary research needs, knowledge gaps, and uncertainties associated with pallid sturgeon recovery efforts. Participants considered the mainstem and the lower tributaries of the Missouri River. This report provides the results of the workshop held in Bloomington, Minnesota, on May 18-20, 2004. Results from the workshop transmitted though this report are intended to identify research needed to aid pallid sturgeon recovery in the Missouri River basin.

Research and assessment needs outlined herein are intended to complement, not supersede or replace, previous efforts at identifying actions for pallid sturgeon recovery (e.g., Graham et al. 1995; USFWS 1993, 2002; Webb et al. 2004). Moreover, we intentionally make no recommendations as to who should conduct this research. Rather, we anticipate that agencies and stakeholders within the basin will collaborate to enlist the skills of diverse qualified experts from a range of agency, university, and private sources and carefully evaluate their performance within the context of explicit and pertinent objectives.

Workshop Organization

Organization

The workshop was organized and facilitated by the University of Wyoming's William D. Ruckelshaus Institute of Environment and Natural Resources in collaboration with an interagency Steering Committee. Members of the Steering Committee included Carl Korschgen (USGS), David Galat (USGS), Doug Latka (USACE), Steven Krentz (USFWS), Michael Oetker (USFWS), Michael Olson (USFWS), Charles Scott (USFWS), and Jim Berkley (USEPA).

Most sturgeon populations in North America have drastically declined, many receive federal protection, and all face issues similar to the endangered pallid sturgeon. As a result, the Steering Committee convened a diverse group of scientists familiar with sturgeon ecology and research from throughout the United States. This diverse group was viewed as necessary to identify novel approaches and ideas related to pallid sturgeon recovery. Most sturgeon experts from outside the Missouri River basin lack personal or affiliation-driven bias with respect to pallid sturgeon and their participation helped maintain an objective atmosphere for the workshop. In addition to the invited technical experts, the workshop was announced and open to the public to establish a transparent process and encourage participation by stakeholder groups.

Thirty-six invited technical experts and 11 observers (stakeholders from interested agencies and the public) from 18 states participated in the workshop in addition to the Steering Committee and workshop organizers (see Appendix A for contact information). Participants included representatives from state and federal agencies, universities, and private organizations. A series of opening plenary session presentations introduced participants to management of pallid sturgeon in the Missouri River basin and to the goal, objective, and organization of the workshop (see Agenda, Appendix B). Facilitated discussion groups were then used as the primary tool to accomplish the goal and objective of the workshop. Participants were assigned to one of three breakout groups: (1) Reproduction, Propagation, and Genetics; (2) Physical Habitat and Flow; or (3) Life History Characteristics, Growth, and Population Assessment.

Goal and Objective

The goal of the workshop was to identify high priority research needed to improve our knowledge of pallid sturgeon ecology and subsequently enhance recovery of this species in the Missouri River system (Table 1). The specific objective of the workshop was to obtain input from regional and national sturgeon experts to better understand critical ecological and other factors influencing pallid sturgeon and how those factors are affected by river operations and management. Participants were asked to collaboratively identify major research needs, knowledge gaps, and uncertainties associated with pallid sturgeon recovery in the Missouri River.

Table 1. Workshop goal, objective, and charge.

Goal—Identify and prioritize research needs that, once met, could improve management and assist recovery of pallid sturgeon in the Missouri River.

Objective—Obtain input from sturgeon experts to understand critical ecological and other factors that influence pallid sturgeon in the Missouri River and how those factors are affected by river operations and management. Research needs should be considered within an adaptive management framework to address potential management experiments within two-year and longer-term timeframes.

Charge—Work collaboratively to create a list of high-priority research needs associated with pallid sturgeon recovery in the Missouri River.

Charge to Participants

On the first day, breakout groups were charged with developing a list of high priority research needs (see discussion summaries in Appendix C). To develop the list, each participant was asked to provide one or two key research needs or sources of uncertainty related to pallid sturgeon recovery or management of the river. After discussion of the list of key issues, research needs were presented to the entire group of participants in a plenary session where ideas were further discussed (Appendix D). During the second day of the workshop, participants returned to the same breakout groups and were challenged to identify testable research hypotheses related to key research needs identified on the first day, and short-term (two years) testable hypotheses related to test flow releases from Fort Peck and Gavins Point dams and the construction of shallow-water habitats in the lower Missouri River downstream of Gavins Point Dam (see Figure 1, page 6). Similar to the first day, each breakout group presented their results to all workshop participants in a plenary session.

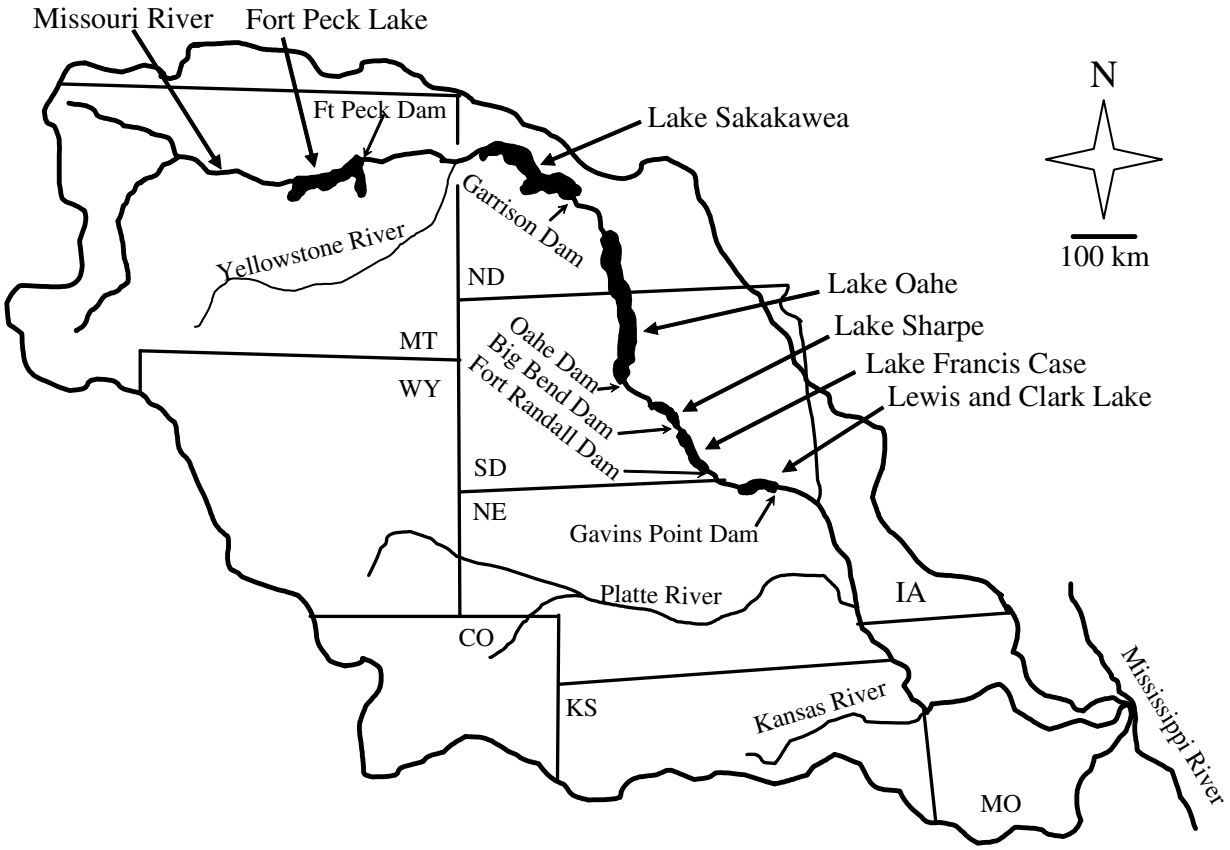
The focus on test flows was in response to planned hydrologic manipulations by the USACE as directed by the 2000 and 2003 Biological Opinions (USFWS 2000, 2003). Because the details of flow releases are flexible, the steering committee hoped that technical experts would provide guidance on what research and evaluation is needed to gain critical knowledge on pallid sturgeon responses to experimental flow releases. The focus on active construction of shallow-water habitats was in response to current habitat manipulation efforts in the lower Missouri River. Specifically, the USACE has initiated a series of activities aimed at increasing habitat through wing-dike and revetment removal and construction of instream structures that promote creation of shallow-water habitats.

On the last day, a public information exchange was held to inform stakeholders on the important concepts that emerged from the workshop and to hear and discuss their ideas and concerns (Appendix E).

Report Review Process

The authors of this report identified the highest priority research needs based on presentations each breakout group made during plenary sessions and a thorough review of all discussions held during the workshop. A draft of this report was reviewed by Steering Committee members, workshop participants and observers, and independent technical experts including the Missouri River Natural Resources Committee (MRNRC; a consortium of state and federal biologists with fish and wildlife management responsibilities for the river). Techniques or ideas contributed by reviewers for the research needs covered at the workshop are included in Appendix F and responses from the MRNRC are shown in Appendix G.

Figure 1. Missouri River basin showing U.S. Army Corps of Engineers mainstem dams and reservoirs.



Summary of Opening Plenary Session Presentations

Welcome

Charles Wooley, Deputy Regional Director for Region 3, USFWS, opened the workshop by welcoming everyone to the Twin Cities. He thanked the USACE for funding the workshop, the USGS for organizing it, and everyone for attending. He noted that this is an excellent opportunity for collaboration and for developing a common vision, and emphasized that this is an important first step in developing a sturgeon research strategy that will allow better river management and will assist with recovery of the species.

Agency Roles in Management and Restoration of Pallid Sturgeon in the Missouri River

U.S. Environmental Protection Agency (USEPA)

Jim Berkley, Missouri River Basin Coordinator for Region 8, discussed responsibilities of the USEPA within the context of pallid sturgeon recovery efforts. The primary responsibility of the USEPA is to maintain and restore water quality through implementation of the Clean Water Act. States have a responsibility to administer water quality standards and the USEPA ensures that the standards are adequate. When approving standards established by the states, USEPA consults with state and federal agencies (e.g., USFWS) to identify potential conflicts with fish and wildlife conservation efforts. Moreover, the USEPA is responsible for resolving interstate water quality conflicts and is focused on ecosystem and watershed recovery efforts. Thus, the USEPA has a direct role for resolving interstate and intrastate concerns related to the biological and physical characteristics of streams and rivers. Many of the concerns directly or indirectly influence pallid sturgeon recovery, such as the regulation of sediment, temperature, and contaminants. Based on these considerations, the USEPA hoped to receive input from participants that could be used in their efforts to restore the Missouri River system and pallid sturgeon.

Missouri River Natural Resources Committee (MRNRC)

A brief description of the MRNRC and written statement prepared by seven state management agencies was presented by Gerald Mestl, Missouri River Program Manager for the Nebraska Game and Parks Commission. The MRNRC is a non-profit organization whose role is to facilitate a system-wide approach to river management and to coordinate research in the Missouri River basin. The MRNRC is concerned with federal- and state-listed species and other trust resources. State agencies issue collection

permits for research activities, illustrating the need for close coordination between researchers and state agency personnel. Many within the MRNRC believe that research is being used to delay management decisions and that research should supplement management, not replace management efforts in the basin. With regard to experimental test flows, the MRNRC believes that test flows should be conducted as soon as possible rather than relying on opportunistic research associated with stochastic high-flow events. The MRNRC contends that existing conditions in the Missouri River system are not suitable for pallid sturgeon recovery and that research should focus on pallid sturgeon biology within the context of flow modifications. Propagation efforts, stocking, and population monitoring are high priorities to state management agencies. Although research is important, it is just one component of pallid sturgeon recovery. Therefore, states will be hesitant to support low-priority research activities when higher-priority needs are not being addressed. The MRNRC hoped these concerns would be considered by participants during the course of the workshop.

U.S. Geological Survey (USGS)

Michael Mac, Director of the Columbia Environmental Research Center, discussed the role of the USGS in pallid sturgeon recovery. The USGS is the primary science and research agency within the U.S. Department of Interior (USDOI). Thus, one of the primary responsibilities of the USGS is to provide technical and research assistance to other USDOI agencies. Most USGS research focuses on applied management problems, but the USGS also recognizes the need for a broad understanding of entire ecosystems. Because issues facing the Missouri River and pallid sturgeon recovery are highly complex, Mac stressed the importance of input provided by participants for guiding research and management activities in the basin. He also noted the value of having a diverse group of sturgeon experts, some of whom have not been directly involved in pallid sturgeon recovery efforts, to provide a fresh look at old problems. Lastly, participants were asked to constructively challenge current management and research activities in the basin.

U.S. Fish and Wildlife Service (USFWS)

Mary Henry, Assistant Regional Director for Ecological Services in Region 6, described that the primary responsibility of the USFWS is to manage and coordinate activities related to pallid sturgeon recovery efforts. The USFWS has rendered a Biological Opinion in response to a request from the USACE for formal consultation which identifies several "Reasonable and Prudent Alternatives" regarding flow manipulations, habitat construction, population monitoring, and research activities. Although the Biological Opinion is no longer open for debate, the USFWS has offered the USACE an opportunity to consider different flow alternatives over the next two years. In two years, a default prescriptive flow suggestion takes effect and provides the cornerstone for an adaptive management process. Participants were asked to keep the flow experiments in mind during discussions and to consider both short- and long-term research needs. The USFWS urgently needs information that will change the trajectory of extinction for pallid sturgeon. Therefore, workshop participants were encouraged to work collaboratively, remain open to the ideas and opinions of other experts, and to focus on the needs of the Missouri River and pallid sturgeon.

U.S. Army Corps of Engineers (USACE)

Doug Latka, Fisheries Biologist, Northwest Division, provided the perspective of the USACE with regard to the Missouri River and pallid sturgeon recovery. He provided a general overview of the existing Missouri River Mainstem Reservoir System and downstream Bank Stabilization and Navigation Projects and their operation to meet multiple Congressionally authorized project purposes. These purposes include hydropower, flood control, irrigation, navigation, recreation, water supply, water quality, and fish and wildlife. The USACE has received a Biological Opinion from the USFWS that recommends actions to ensure that operation of the Corps' Missouri River projects does not jeopardize the continued existence of the pallid sturgeon. However, the Biological Opinion also describes uncertainty related to pallid sturgeon ecology and recovery. In the Biological Opinion, the USFWS outlined a default flow regime that will be implemented by 2006 if an alternative flow plan is not identified that will better serve project purposes while still precluding jeopardy. Latka presented several management opportunities in relation to experimental flow releases and construction of shallow-water habitats (Table 2). The USACE hoped that workshop participants would provide direction on the research needed to reduce uncertainty related to flow and habitat modification.

Table 2. Examples of management consideration in the Missouri River system

- Opportunities exist over the next two years to investigate the range of existing hydrographs in various river reaches and their effect on pallid sturgeon.
- The opportunity also exists to modify the default flow plan identified by the U.S. Fish and Wildlife Service in the 2003 Amended Biological Opinion immediately below Gavins Point Dam (the most altered hydrology and the most unaltered habitat in the lower Missouri River). The experiment involves a more naturalized hydrograph, which includes bimodal peaks.
- In addition, the lower 1,300 km of the Missouri River (downstream of Sioux City, Iowa) are highly channelized, resulting in a uniform trapezoidal channel. Habitat modifications are taking place throughout this zone to increase in-channel habitat diversity.

Overview of Pallid Sturgeon Recovery Efforts

Steve Krentz, Pallid Sturgeon Recovery Team Leader (USFWS), summarized current state-of- knowledge on the ecology of pallid sturgeon in the Missouri and Mississippi river basins and reviewed current research and recovery efforts. These efforts include hatchery propagation and population augmentation, genetic research focused on hybridization, and a variety of projects designed to monitor habitat use and movement. An important focus of the presentation was that pallid sturgeon populations in different portions of the system are facing different recovery issues. Hybridization appears to be an issue in the Mississippi River and lower Missouri River basin, whereas recruitment failure is a concern in other areas. Despite differences among areas, a great deal of

uncertainty related to pallid sturgeon recovery efforts is common to all areas. Workshop participants were challenged to identify research that would reduce uncertainty surrounding pallid sturgeon recovery and management of the Missouri River system.

Connecting "Best Available Science" to Policy Decisions: Lessons Learned from CALFED

To provide an outside perspective on adaptive management and scientific uncertainty related to similarly complex issues, Samuel N. Luoma, Senior Research Hydrologist (USGS), was invited to speak on his experience with California's CALFED Bay-Delta Program (the title CALFED reflects the consortium of California and Federal agencies participating in this effort). CALFED is a multi-billion dollar state and federal agency effort to restore ecological health and improve water management in the San Francisco Bay/Sacramento-San Joaquin Delta estuary.

Similar to issues in the Missouri River basin, the CALFED project dealt with impoundments, hatcheries, and habitat restoration activities and was created from controversy among management agencies and stakeholder groups. Many of the difficulties and complexities associated with CALFED stemmed from policy questions that included important scientific uncertainties. The role of science is often viewed as a process that reduces uncertainty in making management decisions. However, science can lose credibility with stakeholders and policy makers when scientists become advocates; especially when that leads to not clearly defining uncertainty in all interpretations, and identifying the sources of that uncertainty. Scientists may not agree on interpretations, but often agree on the reasons for uncertainty. Perhaps counterintuitively, focusing on uncertainty and identifying the next steps in addressing uncertainties can be productive in bringing all parties into a constructive debate and ultimately finding common ground to address those uncertainties in policy.

Luoma also discussed some important components in integrating science and policy. The first step is to appropriately frame the charge so that advocacy and personal or affiliation-driven agendas do not dominate discussions. The charge must identify policy questions and ask addressable scientific questions related to those policy needs. Science questions and policy questions are inherently different, but the goal is for everyone to see the connection. Attempting to develop a common understanding among all parties of the current state of knowledge is also an important part of discussing knowledge gaps and identifying uncertainties. Research should not just address immediate, short-term opportunities (although these are important). It must also include a progressive attack on the more difficult problems if they are of demonstrated importance to policy (i.e., short term and long term research is needed). A critical component of the process is frequent discussion of progress, not just among scientists, but to include mangers, policy-makers, and stakeholders. Formal, annual reviews of progress, perhaps to include a standing committee of independent expert advisors from outside the system, can be very beneficial in maintaining communication, soliciting new ideas, and implementing aspects of adaptive management. Because pallid sturgeon recovery is a highly complex issue, Luoma stressed the need to focus systematically and to repeatedly evaluate progress in pallid sturgeon recovery, as well as the more basic science issues, as policies are implemented.

Research Needs, Knowledge Gaps, and Uncertainties

Workshop participants were assigned to one of three breakout groups where major research needs, knowledge gaps, and uncertainties related to pallid sturgeon recovery efforts were identified. After each breakout session, all workshop participants met together in a plenary session to discuss their results. All of the identified research needs were considered important and some of the breakout groups found it difficult or were reluctant to prioritize their lists. Based on breakout group reports and a thorough review of the discussion summaries (see Appendices C and D) after the workshop, the authors of this report synthesized the commonalities among groups as they relate to broad topical areas. While almost all research needs can be considered critical or high priority, those that emerged as highest priority are noted in the boxes for each section.

Life History Stages and Events

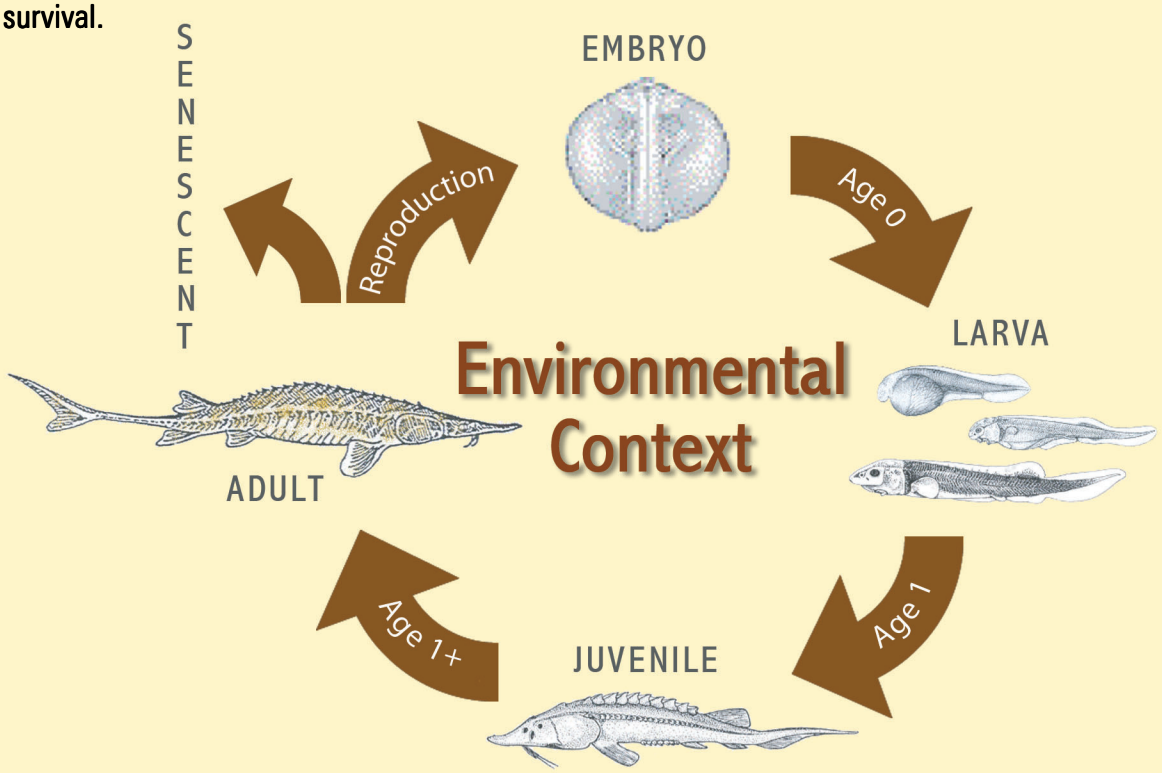
Growth, recruitment, and mortality are the three primary factors regulating population dynamics and thereby influence the conservation and management of fish populations (Ricker 1975). Understanding factors related to growth is important because it provides an integrated evaluation of environmental conditions and genetic factors, and may reflect potential problems or provide feedback on management activities. Recruitment is commonly viewed as the governing and most variable component of fish population dynamics (Gulland 1982). Mortality rate information is also important for conservation and management in providing insight on the effects of biological interactions and the physical environment.

Recruitment is considered a major source of uncertainty that often hinders conservation and management decisions due to difficulties associated with disentangling the complexity of recruitment dynamics and quantifying recruitment variability. Although recruitment may largely govern fish population dynamics, understanding growth and mortality is still critical because they have direct and indirect effects on recruitment. For instance, growth and mortality can influence recruitment by altering age at maturity, fecundity and fish health, and age and size structure of populations, or by regulating survival through critical life-history events.

These considerations are especially pertinent to pallid sturgeon recovery because little is known about critical factors influencing their growth, recruitment, and mortality.

Consequently, workshop participants identified a number of critical research needs associated with growth, recruitment, and mortality within the framework of discrete life history stages (see Figure 2). These stages can be broadly defined as reproduction, age 0 (egg to age 1; by convention, all fish that hatch during a given calendar year are considered to be age 1 on January 1st of the following year), and age 1 and older. Although important life history stages and events could be further defined (e.g., post-larvae), these general categories serve to capture major sources of uncertainty associated with pallid sturgeon recovery. The following discussion outlines major concepts and research needs identified by workshop participants within the context of these general life-history categories. A multitude of ideas were generated by workshop participants (Appendix C), but only research needs of critical importance will be discussed here.

Figure 2. Conceptual model of pallid sturgeon life history. Environmental factors (biotic and abiotic) that reduce survival at any life stage may jeopardize reproductive success and population survival.



Reproduction

Pallid sturgeon spawn during spring and early summer and are thought to deposit eggs over gravel or other rocky substrates (Gilbraith et al. 1988). Age at sexual maturation is largely unknown, but some estimates indicate that males mature in 7 to 9 years and females mature in 15 to 20 years (Keenlyne and Jenkins 1993). Gamete development is extended over several years with an estimated 2 to 3 year interval between spawnings for males and a 3 to 10 year interval for females. Although knowledge on the spawning ecology of pallid sturgeon has increased recently, many basic aspects of maturation and reproduction are unknown.

Environmental Cues. Successful spawning is a requisite for population persistence and insufficient spawning by pallid sturgeon is considered a major hindrance to their recovery in the Missouri River basin. All breakout groups concluded that environmental cues necessary for maturation and spawning are poorly understood. Participants identified photoperiod, thermal characteristics, and discharge as the most likely factors influencing reproduction, both with respect to the physiological mechanisms associated with egg development and eliciting a spawning event. Current flow and thermal regimes in the Missouri River may be inadequate for spawning in some reaches, thus understanding environmental cues associated with maturation and reproduction is critical for recovery efforts. It was noted that shortnose sturgeon (*Acipenser brevirostrum*) adults are known to return to the same spawning areas every year and evidence suggests that imprinting, probably at hatching, is part of this homing behavior. Workshop participants identified a need to determine whether imprinting and homing occur in pallid sturgeon and if so, the significance of these behaviors.

Contaminants. Pollution and contaminants have continued to increase in the Missouri River basin as result of increased urban and agricultural development in the system (USFWS 2000, 2003). Although the accumulation and effects of contaminants on pallid sturgeon are poorly understood, heavy metals (e.g., mercury, cadmium, selenium), polychlorinated biphenyls (PCBs), and pesticides (e.g., chlordane) have been detected in pallid sturgeon tissues (Ruelle and Keenlyne 1994). The prolonged maturation cycle of pallid sturgeon coupled with contaminants could lead to altered reproductive development and reduced spawning. Consequently, examining the influence of contaminants on the reproductive ecology of pallid sturgeon was identified as a critical research need by workshop participants.

Spawning Habitat. Assuming that fish have reached sexual maturity, suitable spawning habitat must be present for successful reproduction. Like the eggs of other acipenserids, pallid sturgeon eggs are demersal (i.e., sink) and adhesive. Although pallid sturgeon are thought to spawn over hard substrates (e.g., gravel, cobble), the specific habitat (e.g., substrate, water velocity, sediment characteristics) selected by pallid sturgeon for egg deposition is unknown. Workshop participants stated that research should identify the habitat requirements necessary to elicit egg deposition. Research should also document the occurrence, quantity, and spatial distribution of potential spawning habitat in the

Missouri River. The structure and function (abiotic and biotic) of large rivers are largely regulated by tributaries; therefore, participants recommended that efforts to characterize spawning habitat should extend to major tributary systems of the Missouri River.

Box 1: Highest priority research needs associated with reproduction of pallid sturgeon*

1.1. Develop a better understanding of environmental factors influencing maturation and spawning movements including homing

1.2. Determine factors that elicit spawning and egg deposition

1.3. Determine the specific locations and microhabitat features associated with spawning

1.4. Identify use and availability of spawning habitat in the Missouri River and its tributaries

1.5. Evaluate the effects of contaminants on reproduction

*These research needs are not ranked.

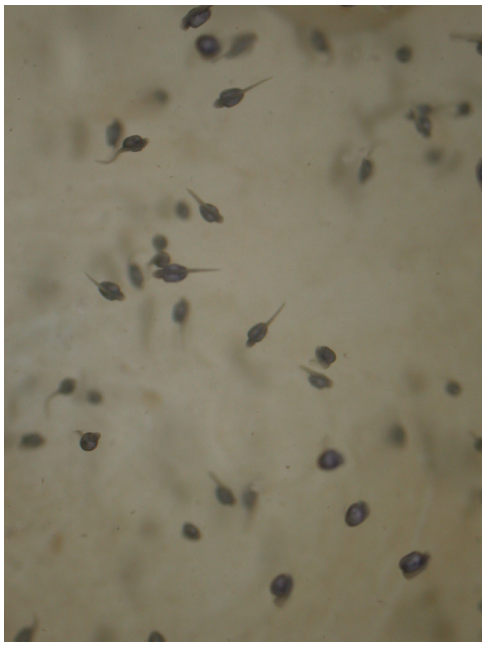
Age 0 characteristics

Early life-history stages are often considered critical in the life cycle of fishes (Cushing 1990). Not only are early life-history stages highly susceptible to environmental stressors, but fish have evolved such that critical ontogenetic (i.e. life stage) events (e.g., diet shifts, changes in body form) are tightly coupled with changes in environmental conditions. Disruptions in environmental conditions, both biotic and abiotic, can have a significant influence on growth, recruitment, and mortality. Despite the importance of early life-history events, little is known about the early life history of pallid sturgeon. Like other fishes, larval pallid sturgeon ontogeny progresses from hatching to endogenous feeding on yolk reserves to exogenous feeding. Immediately after hatching, larval acipenserids are generally pelagic, buoyant, and active. There is a need to determine if imprinting occurs in larval fish and if so, its significance. Although the behavior of larval pallid sturgeon is poorly understood, recent research indicates that larval pallid sturgeon drift downstream for approximately 8 to 13 days after hatching and then settle into benthic habitats (Kynard et al. 2002). Thus, a free-flowing, geomorphically complex river downstream from spawning areas is an important component of age-0 sturgeon. Exogenous feeding (i.e., no longer relying on internal yolk reserves) occurs at 10 to 14 days (at 17-18°C) based on research with cultured fish,. Although the entire early life history is important, initiation of exogenous feeding is particularly important because adequate prey resources (type, abundance, size) must be available where and when larvae settle.

Given the importance of early life-history stages, workshop participants identified a number of research needs, knowledge gaps, and uncertainties associated with age-0 pallid sturgeon.

Egg Survival. Critical factors to consider for egg survival included substrate composition and quality (e.g., sedimentation), the presence and effects of contaminants, bedload activity that might mechanically destroy developing eggs, and consumption of eggs by other fishes.

Yolk Reserves. Once fish hatch, yolk resources must be sufficient to promote growth and survival to when they begin exogenous feeding. Suboptimal energy reserves due to poor condition of females or vertical transmission of contaminants could have deleterious effects on growth and survival of larvae. Consequently, workshop participants considered understanding potential effects of deficient or contaminated yolk reserves to be of critical importance.



Larval pallid sturgeon. *Photo courtesy of U.S. Fish and Wildlife Service.*

Habitat Use and Dispersal. A variety of uncertainties related to larvae as they settle from the drift and begin exogenous feeding were identified. Some research suggests that larval pallid sturgeon are transported to shallow, slow-water habitats (e.g., eddy pools, downstream tips of sandbars and islands; USFWS 2000, 2003). Larval *Scaphirhynchus* sturgeon begin to appear in trawl catches in the middle Mississippi River in mid to late May when water temperatures range from 65 to 70 °F (Herzog 2004). Most small sturgeon have been collected at downstream island tips or velocity shelter areas (e.g., inside bends). Herzog (2004) most recently collected high numbers of larval sturgeon in the middle Mississippi proximate to flooded terrestrial vegetation. However, the rarity of larval pallid sturgeon in collections from the Missouri River has lead to high uncertainty regarding habitat use. Consequently, workshop participants identified a need to determine what habitats are used, which of them provide for optimal growth and survival once larvae leave the drift, and availability of vitally important habitats in the system.

Prey Requirements. Similarly, little is known regarding the prey items consumed by larval pallid sturgeon and whether the appropriate types, densities, and sizes are available. Prey requirements, prey availability, and ontogenetic diet shifts were viewed as critical information needs by workshop participants. Insight on prey requirements of larval pallid sturgeon in natural environments is important, and knowledge of prey use is also important for enhancing survival and growth of larval pallid sturgeon in hatchery environments.

Species Interactions. Similar to egg survival, species interactions may be important for larval pallid sturgeon. Predation by, and competition with, other members of the fish assemblage (including larvae, juveniles, adults) for prey resources and habitat may be important for larval pallid sturgeon survival. Workshop participants highlighted potential interactions with exotic species (e.g., Asian carps, rainbow smelt [*Osmerus mordax*]) as particularly important.

Box 2: Highest priority research needs associated with early life history stages of pallid sturgeon*

2.1. Develop a better understanding of factors related to egg quality

2.2. Determine the influence of predators on egg survival

2.3. Determine environmental factors influencing egg survival

2.4. Describe food habitats and determine ontogenetic diet shifts of larvae and age-0 juveniles

2.5. Evaluate the role of prey production and contaminants on growth and survival of larvae and age-0 juveniles

2.6. Examine seasonal habitat requirements and use by larvae and age-0 juveniles

2.7. Determine which habitats are limiting for larvae and age-0 juveniles

2.8. Determine the influence of predators and competitors on larvae and juveniles

2.9. Determine if imprinting occurs, and if so, its significance.

* These research needs are not ranked.

Age-0 Juveniles. A variety of research needs were identified regarding growth and survival of post-larval, but still age-0 juvenile pallid sturgeon. Similar to larvae, habitat and prey requirements for age-0 juvenile pallid sturgeon are unknown. Obtaining this information was viewed as critical for reducing uncertainty associated with pallid sturgeon recovery efforts.

Age 1 and older characteristics

Less uncertainty exists regarding knowledge of age-1 and older pallid sturgeon than for age-0 pallid sturgeon. A variety of studies have used telemetry to monitor movement and habitat use of pallid sturgeon and although habitat use varies by location in the basin, most adult pallid sturgeon are found over small substrates (e.g., sand, fine gravel) in areas with moderate current velocities (e.g., Bramblett 1996, Constant et al. 1997). A number of studies revealed that pallid sturgeon commonly use areas with a diversity of habitat types (e.g., sandbars, side channels; USFWS 2000, 2003). The trophic ecology of juveniles and adults has received less study. Research indicates that macroinvertebrates and fishes were the most important food items in stomachs of age-1 and older pallid sturgeon (e.g., Carlson et al. 1985).

Due to the ease of studying larger pallid sturgeon relative to early life history stages, more is known about the life history characteristics of age-1 and older fish. However, several important questions remain, many of which overlap those associated with early life history stages. In particular, workshop participants stated a need to better understand habitat selection and availability in the system. A variety of studies have identified habitat use of sub-adult and adult pallid sturgeon, but habitat use may not reflect

Box 3: Highest priority research needs associated with age 1 and older pallid sturgeon*

3.1. Define upstream and downstream migration patterns of each life stage

3.2. Describe food habits and determine ontogenetic diet shifts

3.3. Evaluate the role of prey production and contaminants on growth and survival of pallid sturgeon

3.4. Examine seasonal habitat requirements and use by pallid sturgeon

3.5. Determine which habitats are limiting for pallid sturgeon

3.6. Determine the influence of predators and competitors on pallid sturgeon

* These research needs are not ranked.

optimal habitat for growth and survival, particularly considering the rarity of the species, and the highly-disturbed environmental characteristics of the present-day Missouri River. Participants also suggested that we need a better description of pallid sturgeon food habits and more information on ontogenetic diet shifts. Understanding pallid sturgeon trophic ecology will provide insight on the effects of potential prey limitations and habitat requirements in the system.

Additional considerations

In addition to critical factors associated with growth and survival of different pallid sturgeon life history stages, workshop participants identified research needs that transcended each life history stage.

Population Assessment. Participants suggested a need to develop better methods for sampling pallid sturgeon, particularly eggs and larvae. At a minimum, sampling methods need to be standardized and implemented within the basin. Adequate comparisons are currently hindered due to different sampling methodologies and experimental designs. Standardized methods were viewed as critical because they will enable managers to monitor spatial and temporal trends in pallid sturgeon populations throughout their distribution.

Energy Transport. Many research needs identified by workshop participants were related to food (energy) availability and use. Impoundment of the Missouri River has likely reduced nutrient and organic matter inputs to downstream reaches. Channelization and levees below Sioux City, Iowa, have reduced lateral inputs from productive floodplain wetlands. Reduced nutrient inputs from upstream reaches and lateral floodplains could have substantial influences on food webs, with subsequent direct and indirect effects on pallid sturgeon. However, organic debris (e.g., large woody debris) may provide an important source of nutrients and habitat for producers

Box 4: Highest priority research needs associated with population assessment and energy transport*

4.1. Develop standardized protocols for sampling and monitoring all life history stages of pallid sturgeon

4.2. Conduct long-term monitoring of pallid sturgeon populations to determine population status and detect trends

4.3. Examine the role of reservoirs as nutrient sinks and the subsequent effects on pallid sturgeon and other members of the fish assemblage

4.4. Examine the role of energy transport and organic debris on growth and survival of pallid sturgeon

* These research needs are not ranked.

and consumers in the system, particularly in the lower river. Prey production and energy flow influence all life-history stages of pallid sturgeon and other members of the fish assemblage, thus understanding sources of prey production (e.g., organic debris) was identified as critical by workshop participants. When identifying vital habitat features it is very important to include areas of prey production, even if pallid sturgeons are not located in those habitats during surveys.

Habitat Formation and Maintenance

Historically, the Missouri River was a large, dynamic system characterized by a shifting, braided channel with a diversity of habitat types (USFWS 1993). Floodplains, backwaters, chutes, sloughs, islands and sandbars at various seral stages, and main-channel habitat formed a large-river ecosystem that provided important habitat for pallid sturgeon and other native fishes. The system was in a constant state of change, maintained by a variable flow regime, sediment transport dynamics, and interactions with the floodplain. However, pallid sturgeon habitat has been significantly altered by impoundments and channelization. Beginning in the late 1800s, the lower Missouri River was transformed from a diverse, dynamic system into a deep, high-velocity, single channel. Wing dikes, revetments, and levees have concentrated flow, stabilized the channel and banks, and disconnected the river from its floodplain. Impoundments have constrained movement by pallid sturgeon and reservoir regulation has significantly altered the hydrograph, sediment transport dynamics, and thermal regime. As a consequence, approximately 36% of the riverine habitat in the Missouri River has been inundated by reservoirs and converted to lentic habitat, 40% has been channelized, and the remaining 24% has been altered by reservoir operations. Processes that once formed and maintained habitat in the Missouri River have been eliminated or significantly altered, with subsequent deleterious effects to pallid sturgeon and other native species.

Suitable habitat is critical to all life history stages of pallid sturgeon and other native fishes. Therefore, understanding processes responsible for the formation and maintenance of habitat was viewed as a high priority among workshop participants. In particular, participants suggested a need to better understand the geomorphologic processes of the Missouri River within the context of flow variability and sediment transport. The Missouri River historically had a diversity of habitats, spatially arranged in a mosaic of different seral stages that varied from newly-formed sandbars to well-established vegetated islands. Understanding habitat formation and maintenance within the context of spatial and temporal diversity was viewed as critical. An immediate research need identified by participants was to develop a habitat classification system that would allow researchers and managers to identify and map vitally important habitats (e.g., spawning or rearing habitats), document the occurrence and diversity of habitat in different seral stages, and monitor changes in habitat that might occur in response to flow experiments and physical habitat manipulations.

Box 5: Highest priority research needs associated with habitat formation and maintenance*

5.1. Evaluate the role of sediment transport for creation and maintenance of habitat for all life history stages of pallid sturgeon

5.2. Evaluate the role of discharge for creation and maintenance of habitat for all life history stages of pallid sturgeon

5.3. Determine an optimal mosaic of habitats for rehabilitating river biodiversity

5.4. Evaluate the interaction between flow manipulations and habitat improvement activities for creating habitat

5.5. Develop a framework and methodology for habitat classification

5.6. Document the occurrence and distribution of habitat relative to ecological structure and function

* These research needs are not ranked.

Genetics and Hybridization

Hybridization is considered by many ecologists to be one of the greatest threats to the conservation of native species in North America (Perry et al. 2002). Pallid sturgeon recovery efforts are threatened by hybridization with the more common shovelnose sturgeon (*Scaphirhynchus platorhynchus*). As the incidence of hybridization increases, unique qualities of the pallid sturgeon will be lost if the rate of introgression is not reduced. Because pallid sturgeon are not immune to this threat, all breakout groups discussed issues related to hybridization of pallid sturgeon with shovelnose sturgeon.

Hybridization can occur:

- if spawning habitat is altered or limiting;
- if many individuals of one parent species are sympatric with a small number of the other parent species; or
- if suitable habitat is unavailable due to barriers to movement.

All these conditions likely occur within the distributional area of pallid sturgeon and any one condition, or a combination of conditions, could cause a breakdown of mechanisms associated with reproductive isolation between pallid sturgeon and shovelnose sturgeon.

Several groups identified a need to document the causes of hybridization in the lower Missouri River. Although hybridization is a concern for pallid sturgeon recovery, several experts noted that the occurrence and extent of hybridization between pallid sturgeon and shovelnose sturgeon is unknown. Many argued that apparent hybrids (intermediates) may simply reflect natural morphological variation (phenotypic plasticity) within the species.

The technology, methodology, and knowledge required to examine hybridization is currently available to researchers. Based on concerns regarding hybridization, participants came to a consensus that determining the occurrence and frequency of hybridization in the basin is critical. If hybridization is prevalent in the basin, only then should research focus on the mechanisms (e.g., altered habitat, population density effects) promoting a lack of reproductive isolation between pallid sturgeon and shovelnose sturgeon.

Another issue is a need to determine the genetic status of wild and broodstock populations. In addition to providing important information on factors such as gene flow and potential inbreeding and outbreeding depression, knowledge of the underlying genetic structure of wild and broodstock populations will enable scientists to determine the

Box 6: Highest priority research needs associated with hybridization and genetics*

6.1. Identify the occurrence and frequency of hybridization between pallid sturgeon and shovelnose sturgeon

6.2. Identify factors contributing to hybridization between pallid sturgeon and shovelnose sturgeon

6.3. Obtain genetic information for wild and broodstock populations of pallid sturgeon

6.4. Use genetic analysis to maximize genetic variability in fish included in propagation efforts

6.5. Adopt formal protocols for collecting tissue samples and measurements for genetic analyses and systematic studies

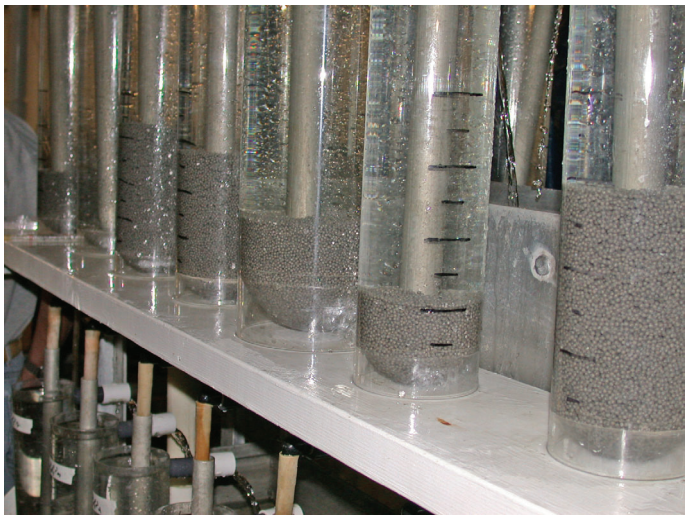
* These research needs are not ranked.

origin (natural versus hatchery) of pallid sturgeon collected from the river. Similar to hybridization, the technology required to conduct the analysis is available. Because many issues, such as stocking success, are dependent on compiling genetic information, participants agreed that collecting and analyzing genetic samples from wild and broodstock populations is critical. Standardized methods are needed for systematic studies, including methods for tissue collection, morphological measurements, and photo vouchering.

Collecting eggs. *Photo courtesy of U.S. Fish and Wildlife Service.*

Propagation and Fish Health

Hatchery propagation of pallid sturgeon has recently been used to supplement wild populations. Although hatchery operations have successfully produced fish for stocking, a variety of questions remain that will help managers improve production and survival of captive fish and their progeny. Questions identified by workshop participants specific to hatchery operations included a need to develop diets that increase growth and survival of pallid sturgeon and reduce nutritional pathologies. Examples of suspected nutritional pathologies include a high incidence of fatty livers and fin curling in captive fish. Another question related to hatchery propagation was a need to determine stocking success. In particular, culturists and managers need information on the best times, locations, and sizes to stock hatchery-reared pallid sturgeon to enhance survival and maximize recruitment to reproductive age. Information is needed on whether imprinting and homing occur and where stocked fish spawn. Most participants agreed that once marking techniques (e.g., genetic marking) are refined and more intensive research occurs, factors related to stocking success will emerge. Evaluating and staging female pallid sturgeon to determine the optimal time for spawning is another research need.



Pallid sturgeon eggs on incubator. *Photo courtesy of U.S. Fish and Wildlife Service.*

Fish health and disease are concerns common to hatchery operations and wild populations. During 1999 and 2000, a new viral pathogen was observed in hatchery-reared pallid sturgeon and shovelnose sturgeon. Infected fish were the progeny of wild pallid sturgeon and shovelnose sturgeon. The pathogen was identified as an iridovirus similar

Box 7: Highest priority research needs associated with propagation and fish health*

7.1. Evaluate and enhance techniques to maximize survival and health of broodstock including developing a diet that provides for healthy growth

7.2. Evaluate and stage female pallid sturgeon to determine optimal time for spawning

7.3. Improve physiological and health tools for maximizing production and survival of eggs

7.4. Develop methods to maximize the efficacy of cryopreservation

7.5. Develop diagnostic tools to evaluate iridovirus

7.6. Identify the occurrence and frequency of iridovirus in wild populations

7.7. Evaluate the effects of iridovirus on all life history stages of pallid sturgeon

7.8. Develop health baselines (e.g., blood chemistry) for all life history stages of pallid sturgeon

* These research needs are not ranked.

to that which infects white sturgeon (*Acipenser transmontanus*) and Russian sturgeon (*A. guldenstadi*; Hedrick et al. 1990, Adkinson et al. 1998). Due to the potential effects of iridovirus on pallid sturgeon, workshop participants recommended that research focus on the effects of iridovirus on all life history stages of pallid sturgeon and its prevalence in wild populations. A prerequisite for conducting such evaluations and making management decisions is developing highly sensitive and accurate diagnostic tools for iridovirus, which was also identified as a critical research need. Similarly, participants suggested that developing health baselines for larval, juvenile, and reproductive adult pallid sturgeon is very important. In particular, baseline hematological factors should be described to aid in evaluations of fish health and physiology.

Short-Term Opportunities

Tasks for breakout groups on the second day of the workshop were to develop testable research hypotheses related to pallid sturgeon recovery that focus on previously identified high-priority research needs. Participants were also asked to identify short-term knowledge gaps and research needs that could be addressed in advance of the anticipated flow test from Gavins Point Dam in 2006 and in response to current construction of shallow-water habitats in the lower Missouri River (see Appendix C). Although a variety of opportunities were discussed, all participants agreed that researchers should use the next two years to plan, design, and implement studies for evaluating effects of flow tests and habitat manipulation activities on pallid sturgeon. Specific research hypotheses are presented in previous sections. The following discussion focuses on the most important issues identified during breakout and group discussions related to flow and habitat manipulations and other projects that could be completed over a relatively short period that were not directly related to flow tests or construction of shallow-water habitats.

Flow manipulations

Workshop participants considered identification of environmental spawning cues as an urgent research need. Many groups suggested that movements of fish in pre-spawning condition should be tracked in areas with different discharge regimes. Monitoring movement of fish experiencing different environmental conditions will help elucidate the best experimental hydrographs to use in flow manipulations. In addition to providing insight on spawning cues, such studies will provide researchers with areas to focus intensive sampling for eggs and early life-history stages. In turn, information on spawning and early life-history characteristics will provide managers with important insights that can be used to guide flow and habitat manipulations.

Most groups suggested that flow manipulations should consider more than just calendar dates in their design. Specifically, experimental flow releases should consider thermal characteristics and sediment dynamics. Experimental flow prescriptions should also be flexible to account for anomalous conditions such as short, warm winters. In addition, manipulated hydrographs should not only consider timing, but also the magnitude, frequency, and duration of releases. Historical (Galat and Lipkin 2000) and Corps of

Engineers modeled (Jacobson and Heuser 2001) Missouri River flow data have been extensively analyzed to compare pre- and post-regulation variability within and among years. Participants suggested that these and other analyses should be capitalized on to provide a clearer picture of the natural flow regime (e.g., spatial and temporal variability) to guide decisions regarding experimental flow releases.

As previously stated, participants were concerned that the current plan for flow releases does not consider thermal characteristics. One idea raised during the breakout session and later presented to the entire group suggested that research on flow and temperature cues for the lower Missouri River might focus on pallid sturgeon in the Fort Randall reach of the Missouri River. The Fort Randall reach is the segment between Fort Randall Dam and Lewis and Clark Lake (formed by Gavins Point Dam). Several reasons were provided to support the utility of focusing on the reach. Pallid sturgeon have been studied in the reach, providing a source of pre-treatment information. The Fort Randall reach is unique in that both discharge and thermal characteristics (powerplant discharges) can be manipulated. From an experimental design perspective, a biological response by pallid sturgeon can be monitored with respect to manipulation of discharge, temperature, or both discharge and temperature. However, there is not agreement that this reach provides an appropriate focused research area (see MRNRC letter in Appendix G).

Box 8: Highest priority research hypotheses related to experimental flow releases*

8.1. Changes in the flow regime enhance pallid sturgeon spawning habitats

8.2. A rise in discharge and temperature during the spring is important for maturation (post-vitellogenesis to spawning)

8.3. Changes in the flow regime enhance the availability and quality of nursery habitats

8.4. A more naturalized hydrograph (magnitude, frequency, duration, timing) will elicit spawning by pallid sturgeon

8.5. A more naturalized hydrograph (magnitude, frequency, duration, timing) will result in pallid sturgeon using previously unutilized riverine habitats

8.6. A more naturalized flow regime will enhance a dynamic channel geomorphology and associated fish habitats

8.7. Test flows downstream of Fort Peck and Gavins Point dams will affect habitat availability for pallid sturgeon, including spawning habitat

8.8. A low flow period will result in increased shallow-water habitat and will increase survival of larval and juvenile pallid sturgeon

* These research hypotheses are not ranked.

Habitat manipulations

A variety of issues were raised about construction of shallow-water habitat in the lower Missouri River. An important point raised by participants was that benefits of habitat manipulations need to be explicitly defined and their performance evaluated. For example, one goal might be to provide habitat for larval and juvenile pallid sturgeon. Alternatively, the goal might be to increase prey production for pallid sturgeon. Therefore, performance criteria for habitat improvement need to be explicitly defined so relevant biological response measures can be developed.

Although shallow-water habitats could have multiple benefits, most participants agreed that the most likely beneficiaries would be the early life-history stages of pallid sturgeon. However, habitat use or selection by larval and juvenile pallid sturgeon is currently unknown. Several groups suggested that a combination of laboratory and field experiments using different life-history stages of pallid sturgeon would help provide engineers with guidance as to how shallow-water habitats should be constructed.

Many scientists also hypothesized that even if habitat is suitable for pallid sturgeon, sampling of shallow-water habitats will likely yield few pallid sturgeon due to their present rarity. Despite this potential limitation, many argued that lack of pallid sturgeon is also important to document because absence of pallid sturgeon might provide insight on habitat avoidance. A very important short-term opportunity identified by workshop participants was the chance to monitor changes in fish assemblage structure associated with constructed habitats. Understanding energy flow and prey production was also identified as very important. Monitoring biological responses of the entire fish assemblage to construction of shallow-water habitats will yield important insights, regardless of whether or not pallid sturgeon are collected over the next few years. It is anticipated that when planned intensive stocking programs are implemented they will increase the number of pallid sturgeon so that their use of rehabilitated habitats can be directly evaluated.

Several groups suggested that both flow and habitat manipulation will be necessary to elicit a substantial change in habitat characteristics. For example, the lower river (channelized areas) is deeply incised as a result of bank stabilization, channel confinement, and reduced sediment transport. Increased flows may do nothing more than transport water, and potentially larval fish, downstream at a high rate with little effect on inriver habitat. However, habitat manipulation conducted in concert with increased flows may increase habitat abundance and diversity for pallid sturgeon. Several groups suggested from a river geomorphology perspective that immediate efforts should describe current habitat conditions such that physical responses can be monitored following flow releases and construction of shallow-water habitats. To adequately describe and document habitat conditions in the system, researchers and managers need a method to quantify current habitat characteristics, as well as monitor changes in habitat availability due to flow releases and construction of shallow-water habitats. Consequently, developing a habitat classification methodology was also viewed as a necessary and achievable short-term opportunity.

Box 9: Highest priority research hypotheses related to construction of shallow-water habitats*

9.1. The current mosaic of habitats is available for pallid sturgeon to complete their life cycle in each segment of the Missouri River

9.2. Constructed shallow-water habitat will be used by larval and juvenile pallid sturgeon during low flow periods

9.3. Flow management and habitat construction activities will maintain riverine habitat thought to be important to pallid sturgeon and will elicit a positive biological response from pallid sturgeon and other native benthic fishes (e.g., increased abundance, growth, recruitment, and survival)

9.4. Test flows, physical habitat modification (e.g., wing dike notching or removal), and tributary inputs downstream of Gavins Point Dam will act in concert to substantially alter channel morphology and will result in a positive biological response from pallid sturgeon

9.5. Missouri River habitats can be organized into a classification system that enables quantification of the extent and temporal trends of each habitat class

* These research hypotheses are not ranked.

Missouri River near Niobrara, Nebraska. *Photo courtesy of U.S. Geological Survey.*

Box 10: General research hypotheses related to pallid sturgeon recovery*

10.1. Key factors cueing the spawning migration of pallid sturgeon include discharge, photoperiod, water temperature, and water quality

10.2. Key factors influencing the selection of spawning sites and areas for egg deposition are substrate characteristics, depth, water velocity, turbulence, water temperature, moon phase, and discharge patterns

10.3. Survival and successful hatching of pallid sturgeon eggs are related to sediment dynamics and substrate characteristics (e.g., size, embeddedness, interstitial spaces), water temperature, water velocity, bedload movement, predation, and the amount of contaminants in the sediment

10.4. Survival and growth of larval and juvenile pallid sturgeon are related to predation and competition, discharge, water temperature, hydraulic patterns and diversity, food availability and selection, habitat availability and selection (including habitat diversity), and contaminants

10.5. Survival and growth of pallid sturgeon from age 0 to age 1 are related to predation and competition, discharge, water temperature, hydraulic patterns and diversity, food availability and selection, habitat availability and selection (including habitat diversity), and contaminants

10.6. Survival and growth of pallid sturgeon from age 1 to age-at-maturity are related to predation and competition, discharge, water temperature, hydraulic patterns and diversity, food availability and selection, habitat availability and selection (including habitat diversity), contaminants, and exploitation

10.7. Trends in presence-absence, population density, age structure, growth, mortality, and recruitment are similar among regions and do not vary through time

* These research hypotheses are not ranked.

Additional short-term opportunities not directly related to flow and habitat manipulations

Research needs discussed by participants focused on growth, recruitment, and mortality of pallid sturgeon in the Missouri River. Although most research needs focused on use and availability of habitat and prey resources and their relation to growth, recruitment, and mortality, development and implementation of standardized sampling protocols was repeatedly voiced as an overriding need. Standardized sampling methodologies, coupled with sound experimental designs, are required to monitor population trends and to evaluate changes in pallid sturgeon populations due to flow and habitat manipulations. Therefore, developing standardized protocols was viewed as a necessary and achievable short-term opportunity.

All breakout groups mentioned hybridization as a concern for pallid sturgeon. Although the tools and techniques required to assess hybridization between pallid sturgeon and shovelnose sturgeon are available, a comprehensive study on hybridization has not been conducted. Therefore, workshop participants suggested that the occurrence and extent of hybridization should be investigated over the next two years. Similarly, the underlying genetic structure of wild and broodstock populations requires additional study. Standardized methods of data collection are needed for all systematic and genetic studies. This research would allow researchers to examine important characteristics related to long-term persistence of wild populations (e.g., inbreeding depression) and enable managers to better evaluate stocking success (e.g., genetic marking of stocked fish).

Inserting tag. *Photo courtesy of U.S. Fish and Wildlife Service.*

Participants identified several issues related to fish disease and hatchery propagation during the course of the workshop. Most issues associated with fish disease focused on iridovirus and developing health baselines. With regard to iridovirus, short-term opportunities include development of diagnostic tools, assessment of transmission routes (e.g., vertical transmission), and evaluation of iridovirus on the health of larval, juvenile, and adult pallid sturgeon. Once reliable diagnostic tools are available, the occurrence and extent of iridovirus in wild populations can be evaluated. Developing health baselines (e.g., blood chemistry) could also be investigated over the short-term and would allow researchers and culturists to better assess the condition of wild and hatchery-reared pallid sturgeon. Participants also suggested that methodologies associated with cryopreservation (i.e., freezing gametes for later use) could be investigated over a short-time period. With regard to hatchery operations, short-term opportunities include an evaluation of the causes, effects, and treatment of fin curling and fatty livers in hatchery-reared pallid sturgeon. Similarly, diets that optimize growth and survival and minimize nutritional pathologies should be developed.

The last major short-term opportunity focused on synthesis of existing data. Many participants provided information and insight on pallid sturgeon (e.g., current research) during the course of the workshop that was previously unknown to the group. In response, participants suggested a need to develop a detailed synopsis or review of pallid sturgeon ecology and research. In particular, the synopsis should outline and describe the current state of knowledge on pallid sturgeon, including past and ongoing research, monitoring, and assessment. Participants believed a synopsis would help to better define uncertainty and generate novel research hypotheses.

Recommended Next Steps

This workshop was an important step in the continuing process of recovering pallid sturgeon in the Missouri River basin. Through discussions among key experts and managers and with input from observers, an extensive set of research needs was identified. The next step is to maintain momentum and build upon this progress to implement critical research needs. Based on presentations and discussions at the workshop and among authors following the workshop, we recommend the following next steps:

1. Collaborate among agencies and stakeholders on prioritizing these research needs, particularly in the context of information needs associated with the planned flow release experiments in 2006 and current construction of shallow-water habitats in the lower Missouri River.

2. Develop guidelines on how research will be conducted and the process for agency and stakeholder cooperation and participation in guiding research activities.

3. Incorporate independent science review (ISR) in research, propagation, monitoring, and management activities. The outline below is a summary of general principles of ISR (adapted from the 2002 National Research Council report, *Review Procedures for Water Resources Project Planning*) that should be used in the design of the independent review approach.

    - An array of inputs should be considered when structuring a review, including stakeholder opinion, agency opinion, client or sponsor opinion, strategic plan, mission and vision.
    - Based on the inputs above, the general scope and goals of the review should be developed.
    - The review should be conducted with an independent organization which selects and establishes an independent review panel (the process for reviewer selection and the reviewers themselves must be as independent of the decision making agency as possible).
    - The agency provides the panel information necessary for conducting the review.

- In addition to receiving viewpoints of the sponsoring agency, the review panel should receive input from relevant stakeholders.
- The panel's conclusions are provided in a final report.
- The agency then responds to the independent review panel's final report.

4. Establish a mechanism for continued stakeholder involvement and information exchange. The Missouri River Recovery Implementation Committee (MRRIC) was proposed in the Master Manual (Final 2004 Master Water Control Manual, U.S. Army Corps of Engineers) and is one approach for stakeholder involvement.

5. Establish a mechanism for coordination, data management, and information exchange among scientists and managers conducting research, propagation, monitoring and assessment of *Scaphirhynchus* sturgeons and implementing and evaluating Missouri River mitigation.

Missouri River near Jefferson City, Missouri. *Photo courtesy of U.S. Geological Survey.*

These steps should be implemented within an adaptive management framework, allowing managers and researchers to adjust priorities if needed as new information becomes available, and to incorporate new information into river management programs.

Many relevant research and monitoring projects have already been conducted or are underway on the Missouri River and similar research needs identified here reinforce the importance of this work. Mitigation projects are predicted to improve habitat for pallid sturgeon, expansion of artificial propagation will enhance sturgeon populations, experimental flow releases will test predicted benefits of a more natural flow regime, and ongoing and proposed monitoring and assessment activities will contribute to determining success of these efforts. Research is an integral part of each of these programs. Viewed holistically, these efforts will collectively define life-history and ecological requirements within a scientifically credible and defensible framework that will be of immense practical value in guiding river operations and management to realize pallid sturgeon recovery.

Acknowledgements

The workshop on *Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River* and publishing of this report were made possible by funding provided by the U.S. Army Corps of Engineers to the U.S. Geological Survey and then to the University of Wyoming through the Rocky Mountain Cooperative Ecosystem Studies Unit, Cooperative Agreement No. 99HQAG0097.

The authors gratefully acknowledge the participants and observers for their commitment to the workshop's objectives and for their review of an earlier draft of this report. We also thank the independent reviewers, Paul Anders, Herb Bollig, Aaron Delonay, Mark Dryer, Rob Klumb, and members of the Missouri River Natural Resources Committee for their contributions to this process.

Literature Cited

Adkinson, M. A., M. Cambre, and R. P. Hedrick. 1998. Identification of an iridovirus in Russian sturgeon (*Acipenser guldenstadi*) from northern Europe. Bulletin of the European Association of Fish Pathologists 18:29-32.

Bramblett, R. G. 1996. Habitat and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota. Doctoral dissertation. Montana State University, Bozeman.

Carlson, D. M., W. L. Pflieger, L. Trial, and P. S. Haverland. 1985. Distribution, biology, and hybridization of *Scaphirhynchus albus* and *S. platorynchus* in the Missouri and Mississippi rivers. Environmental Biology of Fishes 14:51-59.

Constant, G. C., W. E. Kelso, D. A. Rutherford, and C. F. Bryan. 1997. Habitat, movement, and reproductive status of pallid sturgeon (*Scaphirhynchus albus*) in the Mississippi and Atchafalaya rivers. Report to the U.S. Army Corps of Engineers, New Orleans District, New Orleans, Louisiana.

Cushing, D. H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Advances in Marine Biology 26:250-293.

Galat, D. L., and R. Lipkin. 2000. Restoring ecological integrity of great rivers: historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia 422/423:29-48.

Gilbraith, D. M., M. J. Schwalbach, and C. R. Berry. 1988. Preliminary report on the status of the pallid sturgeon, *Scaphirhynchus albus*, a candidate endangered species. Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings.

Graham, K., J. Hamilton, T. Grace, N. Stucky, and B. Hrabik. 1995. An action plan for pallid sturgeon in Missouri. Missouri Department of Conservation, Jefferson City.

Gulland, J. A. 1982. Why do fish numbers vary? Journal of Theoretical Biology 97:69-75.

Hedrick, R. P., J. M. Groff, T. McDowell, and W. H. Wingfield. 1990. An iridovirus infection of the integument of the white sturgeon *Acipenser transmontanus*. Diseases of Aquatic Organisms 8:39-44.

Herzog, D. P. 2004. Large catch of larval sturgeon in Middle Mississippi River provides new information on habitat use in high water conditions. Stages: newsletter of the Early Life History Section of the American Fisheries Society 25(3): 2-4.

Jacobson, R. B., and J. Heuser. 2001. Visualization of flow alternatives, lower Missouri River. Open-file Report OF02-122, U. S. Geological Survey, Columbia, Missouri. Online at: http://www.cerc.usgs.gov/rss/visualize/index.htm

Keenlyne, K. D., and L. G. Jenkins. 1993. Age at sexual maturity of the pallid sturgeon. Transactions of the American Fisheries Society 122:393-396.

Kynard, B.E., E. Henyey, and M. Horgan. 2002. Ontogenetic behavior, migration, and social behavior of pallid sturgeon, *Scaphirhynchus albus*, and shovelnose sturgeon, *S. platorynchus*, with notes on the adaptive significance of body color. Environmental Biology of Fishes 63:389-403.

Perry, W. L., D. M. Lodge, and J. L. Feder. 2002. Importance of hybridization between indigenous and nonindigenous freshwater species: an overlooked threat to North American biodiversity. Systematic Biology 51:255-275.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191.

Ruelle, R., and K. D. Keenlyne. 1994. Contaminant information bulletin: the suitability of shovelnose sturgeon as a pallid sturgeon surrogate. SD-ES-94-03, U.S. Fish and Wildlife Service, Pierre, South Dakota.

U.S. Fish and Wildlife Service (USFWS). 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*). U.S. Fish and Wildlife Service, Denver, Colorado.

U.S. Fish and Wildlife Service (USFWS). 2000. Biological opinion on the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River bank stabilization and navigation project, and operation of the Kansas River reservoir system. U.S. Fish and Wildlife Service, Denver, Colorado.

U.S. Fish and Wildlife Service (USFWS). 2002. Pallid sturgeon recovery needs for RPA 4 and RPA 5 as identified in a survey of the Middle Basin Pallid Sturgeon Recovery Work Group. Columbia Fisheries Assistance Office, Columbia , Missouri.

U.S. Fish and Wildlife Service (USFWS). 2003. U.S. Fish and Wildlife Service 2003 amendment to the 2000 biological opinion on the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River bank stabilization and navigation project, and operation of the Kansas River reservoir system. U.S. Fish and Wildlife Service, Denver, Colorado.

Webb, M.A.H., J.E. Williams and L.R. Hildebrand. 2004. Review of the recovery program for the endangered pallid sturgeon in the upper Missouri River basin. Report prepared by the Western Division of the American Fisheries Society for the Upper Basin Pallid Sturgeon Workgroup. Unpublished report available from the Western Division's website: http://www.wdafs.org/news/2004/WDAFS%20FinalPallid%20Review%20Report.pdf

Appendix A—Contact Information for Workshop Attendees

Alan Allert
U.S. Geological Survey
4200 E. New Haven Rd.
Columbia, MO 65201-9634
alan_allert@usgs.gov

Nancy Auer
Michigan Technological University
1400 Townsend Dr.
Houghton, MI 49931
naauer@mtu.edu

Robert Bacon
MO Dept. of Nat. Res.
P.O. Box 176
Jefferson City, MO 65102
robert.bacon@dnr.mo.gov

Bill Beacom
Nav-Con Services
2423 Jackson St.
Sioux City, IA 51104
bbeacom@pionet.net

Jim Berkley
U.S. Env. Protection Agen.
999 18th St., Ste. 300
Denver, CO 80209
berkley.jim@epa.gov

Pat Braaten
U.S. Geological Survey
East Kansas St.
Fort Peck, MT 59223
patrick_braaten@usgs.gov

Sue Camp
U.S. Bureau of Reclamation
P.O. Box 30137
Billings, MT 59107
scamp@gp.usbr.gov

Doug Carlson
NY Dept. of Environ. Conservation
317 Washington St.
Watertown, NY 13601
dmcarlso@gw.dec.state.ny.us

Joyce Collins
U.S. Fish & Wildlife Serv.
8588 Route 148
Marion, IL 62959
joyce_collins@fws.gov

Roger Collins
U.S. Fish & Wildlife Serv.
3425 Miriam Ave.
Bismarck, ND 58501
roger_collins@fws.gov

Tommie Crawford
MO Dept. of Conservation
RT 5 Box 30A
Warsaw, MO 65355
tommie.crawford@mdc.mo.gov

Jan Dean
U.S. Fish & Wildlife Serv.
615 Hwy 1 South
Natchitoches, LA 71457
jan_dean@fws.gov

Mark Drobish
U.S. Army Corps Engineers
P.O. Box 710
Yankton, SD 57078
mark.r.drobish@usace.army.mil

Grant Feist
Oregon State University
104 Nash Hall.
Corvallis, OR 97331-3803
feistg@onid.orst.edu

David Galat
Univ. of MO/USGS
302 Anheuser-Bush Nat. Res. Bldg.
Columbia, MO 65211-7240
galatd@missouri.edu

Bill Gardner
MT Fish, Wildlife & Parks
P.O. Box 938
Lewistown, MT 59457
fwplew@tein.net

Joanne Grady
U.S. Fish & Wildlife Serv.
101 Park Deville Dr., Ste. A
Columbia, MO 65203
joanne_grady@fws.gov

Chris Guy
Montana State University
301 Lewis Hall
Bozeman, MT 59715
cguy@montana.edu

Ed Heist
Southern Illinois University
LS II Room 173, 1125 Lincoln Dr.
Carbondale, IL 62901
edheist@siu.edu

Mary Henry
U.S. Fish & Wildlife Serv.
Federal Ctr. P.O. Box 25486
Denver, CO 80225
mary_henry@fws.gov

Dave Herzog
MO Dept. of Conservation
3815 East Jackson Blvd
Jackson, MO 63755
david.herzog@mdc.mo.gov

Rob Holm
U.S. Fish & Wildlife Serv.
Box 530
Riverdale, ND 58565
rob_holm@fws.gov

Harold Hommes
IA Dept. Ag. & Land Stew.
E. 9th & Grand Ave, Henry A. Wallace Bldg.
Des Moines, IA 50319
harold.hommes@idals.state.ia.us

Robb Jacobson
U.S. Geological Survey
4200 E. New Haven Rd.
Columbia, MO 65201
rjacobson@usgs.gov

Donald Jorgensen
Lakota Consulting
33599 479 Ave.
Jefferson, SD 57038
donjorg@pionet.net

Jack Killgore
U.S. Army Corps Engineers
3909 Halls Ferry Rd.
Vicksburg, MS 39180
jack.killgore@erdc.usace.army.mil

Carl Korschgen
U.S. Geological Survey
4200 E. New Haven Rd.
Columbia, MO 65201
ckorschgen@usgs.gov

Steven Krentz
U.S. Fish & Wildlife Serv.
3425 Miriam Ave.
Bismarck, ND 58501
steven_krentz@fws.gov

Bernie Kuhajda
University of Alabama
425 Scientific Collections
Box 870345
Tuscaloosa, AL 35487
bkuhajda@bama.ua.edu

Boyd Kynard
U.S. Geological Survey
P.O. Box 796
One Migratory Way
Turner Falls, MA 01376
kynard@forwild.umass.edu

Doug Latka
U.S. Army Corps Engineers
12565 S. Center Rd.
Omaha, NE 68144
doug.c.latka@nwd02.usace.army.mil

Samuel N. Luoma
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
snlumoa@usgs.gov

Steve Lydick
U.S. Fish & Wildlife Serv.
203 W. 2nd St.
Federal Bldg. 2nd Floor
Grand Island, NE 68801
steve_lydick@fws.gov

Michael Mac
U.S. Geological Survey
4200 E. New Haven Rd.
Columbia, MO 65201
mmac@usgs.gov

Gerald Mestl
Nebraska Game & Parks
P.O. Box 30370
Lincoln, NE 68503-0370
gmestl@ngpc.state.ne.us

Jim Michaels
FL Mote Marine Laboratory
1600 Ken Thompson Pkwy
Sarasota, FL 34236
michaels@mote.org

Michael Oetker
U.S. Fish & Wildlife Serv.
1 Federal Way
Fort Snelling, MN 55111
mike_oetker@fws.gov

Michael Olson
U.S. Fish & Wildlife Serv.
3425 Miriam Ave.
Bismarck, ND 58501
michael_olson@fws.gov

Richard Opper
MO River Basin Assoc.
P.O Box 301
Lewistown, MT 59457
rhoper@midrivers.com

Diana Papoulias
U.S. Geological Survey
4200 E. New Haven Rd.
Columbia, MO 65201
diana_papoulias@usgs.gov

Vaughn Paragamian
Idaho Fish & Game
2750 Kathleen Ave.
Coeur d' Alene, ID 83815
vparagamian@idfs.state.id.us

James Parham
University of Nebraska
311 Biochemistry Hall
Lincoln, NE 68583-0759
Jparham2@unl.edu

Mike Parsley
U.S. Geological Survey
5501A Cook-Underwood Rd.
Cook, WA 98605
michael_parsley@usgs.gov

Ed Peters
University of Nebraska
12 Plant Industry Bldg.
Lincoln, NE 68583-0814
Epeters2@unl.edu

Bobby Reed
LA Dept. of Wildlife & Fisheries
1213 N. Lakeshore Dr.
Lake Charles, LA 70601
reed_bc@wlf.state.la.us

Charles Scott
U.S. Fish & Wildlife Serv.
101 Park Deville Dr., Ste. A
Columbia, MO 65203
charlie_scott@fws.gov

Maryetta Smith
U.S. Army Corps Engineers
P.O. Box 80
Vicksburg, MS 39181-0080
maryetta.smith@mvd02.usace.army.mil

Wayne Stancill
U.S. Fish & Wildlife Serv.
420 S Garfield Ave, Rm 400
Pierre, SD 57501
wayne_stancill@fws.gov

Nick Stas
Western Area Power Admin.
P.O. Box 35800
Billings, MT 59107
STAS@wapa.gov

Bill Wayman
U.S. Fish & Wildlife Serv.
5308 Spring Street
Warm Springs, GA 31830
william_wayman@fws.gov

Molly Webb
Oregon State University
104 Nash Hall
Corvallis, OR 97331
molly.webb@oregonstate.edu

Mark Wildhaber
U.S. Geological Survey
4200 E. New Haven Road
Columbia, MO 65201
mark_wildhaber@usgs.gov

Cindy Williams
U.S. Bureau of Reclamation
P.O. Box 36900
Billings, MT 59107
cwilliams@gp.usbr.gov

Rob Wood
Saint Louis University
3507 Laclede
St. Louis, MO 63104
wood2@slu.edu

Charles Wooley
U.S. Fish & Wildlife Serv.
1 Federal Drive
Fort Snelling, MN 55111
charles_wooley@fws.gov

Workshop Organizers

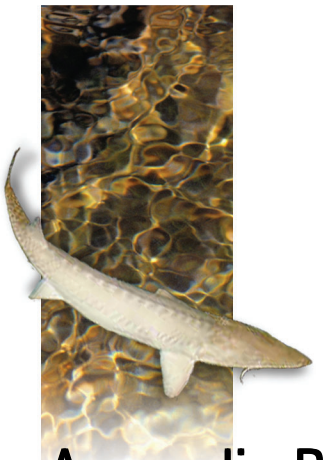
Harold Bergman
William D. Ruckelshaus Institute
Environ. & Nat. Res.
University of Wyoming
Dept. 3971
1000 E. University Ave.
Laramie, WY 82071
bergman@uwyo.edu

Ann Boelter
William D.Ruckelshaus Institute
Environ. & Nat. Res.
University of Wyoming
Dept. 3971
1000 E. University Ave.
Laramie, WY 82071
boelter@uwyo.edu

Nicole Korfanta
William D. Ruckelshaus Institute
Environ. & Nat. Res.
University of Wyoming
Dept. 3971
1000 E. University Ave.
Laramie, WY 82071
korfanta@uwyo.edu

Jill Lovato
William D. Ruckelshaus Institute
Environ. & Nat. Res.
University of Wyoming
Dept. 3971
1000 E. University Ave.
Laramie, WY 82071
jillberg@uwyo.edu

Michael Quist
Wyoming Coop. Fish & Wildlife
Res. Unit
University of Wyoming
Dept. 3166
1000 E. University Ave.
Laramie, WY 82071
mcquist@uwyo.edu



Appendix B—Agenda

Agenda

Pallid Sturgeon Research Workshop
Tuesday, May 18, 2004 – Thursday, May 20, 2004
Embassy Suites Hotel
2800 American Boulevard West
Bloomington, MN

Tuesday, May 18, 2004

8:00am **Welcome and Introductions**—Harold Bergman, UW Ruckelshaus Institute

8:20am **Welcome and Remarks**—Charles Wooley, Deputy Regional Director, Region 3, U.S. Fish and Wildlife Service (USFWS)

8:30am **Meeting Organization/Structure/Goals/Objectives**—Harold Bergman

8:45am **Panel Review: Agency Roles in Management/Restoration of the Missouri River's Pallid Sturgeon**—Panelists: Jim Berkley, U.S. Environmental Protection Agency (EPA); Gerald Mestl, Missouri River Natural Resources Committee (MRNRC); Mike Mac, U.S. Geological Survey (USGS); Mary Henry, USFWS; Doug Latka, U.S. Army Corps of Engineers (ACOE)

9:15am **Overview of Pallid Sturgeon Recovery**—Steve Krentz, USFWS

9:35am **Connecting "Best Available Science" to Policy Decisions: Lessons Learned from CALFED**—Sam Luoma, USGS

10:00am **Charge to Participants**—Harold Bergman

10:15am **Questions and Comments from Observers**

10:30am Break

10:45am Breakout Session I

***Note:** Participants will break into assigned discussion groups: a) Reproduction/ Propagation/Genetics, b) Life History/ Growth/Population, and c) Habitat/Flow. Each breakout group will discuss their assigned topic and identify research gaps and needs associated with pallid sturgeon management.

12:00pm **Buffet Lunch Served in Main Meeting Room: Breakout Session I Continues**

3:00pm **Break**

3:15pm **Plenary Session/Group Discussion of Breakout Reports**

Group will reconvene. Breakout groups will report on their discussion. Participants will comment and ask questions to help refine breakout findings. Group will create an initial prioritized list of management needs and research gaps.

5:00pm **Questions and Comments from Observers**

5:15pm **Meeting Adjourns for Dinner**

7:00pm **Group reconvenes—Facilitated Open Discussion**

Group will reconvene. Discussion will focus on the following points in both the short-term and longer-term contexts:

- Identification of major issues/topics for Wednesday Breakout Groups
- Integrating management needs into adaptive management framework

9:00pm **Meeting Adjourned for the Evening**

Wednesday, May 19, 2004

8:00am **Breakout Session II**

Participants will be reassigned to new breakout groups based on discussion topics listed in previous plenary session.

10:00am **Break**

10:15am **Continue Breakout Session II**

12:00pm **Buffet Lunch Served: Plenary Session**

Lunch will be served and breakout groups will return to plenary session. Breakout groups will report on their discussions and participants and observers will comment and ask questions to help refine breakout finding.

1:45pm **Questions and Comments from Observers**

2:00pm **Break**

2:15pm **Plenary Session Continues**

3:00pm **Questions and Comments from Observers**

3:15pm **Plenary Discussion and Conclusions: Draft Research Priority List**

4:15pm **Closing Remarks**—Harold Bergman

4:30pm **Meeting Adjourned**

Thursday, May 20, 2004

9:00am **Public Stakeholder Information Exchange**—Harold Bergman (Facilitator)

An open dialogue will take place among the workshop steering committee, participants, and members of the public regarding the initial proceedings of the workshop.

12:00pm **Meeting Adjourned**

Appendix C— Summary of Breakout Sessions

The following sections contain bulleted lists of research needs. Each breakout group reported back to the plenary session. Based on those reports and a thorough review of the discussion summaries after the workshop, the authors of this report distilled the high priority needs shown in italics in each list.

Summary of Breakout Group I: Reproduction, Propagation, and Genetics

Participants:

- Alan Allert, Tommie Crawford, Jan Dean, Mark Drobish, Grant Feist, Ed Heist, Rob Holm, Bernie Kuhajda, Jim Michaels, Diana Papoulias, Molly Webb, Bill Wayman, Rob Wood
- Harold Bergman (facilitator), Mike Mac (recorder)

The first task assigned to the group was to identify two research needs or information gaps related to pallid sturgeon reproduction, propagation, or genetics. After each participant provided their input, research needs and information gaps were categorized as belonging to one of six topical areas: (1) hatchery propagation, (2) physiology and nutrition, (3) fish health and disease, (4) natural reproduction and recruitment, (5) genetics and hybridization, and (5) other issues.

Hatchery propagation

Research needs associated with hatchery propagation reflected general issues related to maintaining broodstock populations, handling fish and eggs, and developing tools that enable fish culturist to maximize survival, production, and efficiency at each step in the propagation process. High priority research needs included a need to develop, evaluate, and enhance techniques that maximize survival and health of broodstock populations. In particular, participants identified a need to develop methods for reducing handling stress and tools that enable culturists to assess physiological stress, reproductive status, and overall health of broodstock populations. Another equally important and similar research need was identified as the development of tools and methods that improve production and survival of eggs. Participants also identified a need to maximize the efficacy of cryopreservation methodologies. The last group of high priority research

needs focused on the optimal size of hatchery-reared fish for stocking and their contribution to wild populations. A variety of other research needs were identified that provide additional avenues for research. In particular, participants illustrated the need to use experience and knowledge gained by professionals associated with propagation of other sturgeon species to benefit pallid sturgeon recovery efforts.

- *Evaluate and enhance techniques to maximize the survival and health of broodstock (e.g., handling stress, physiologic and health tools) including developing a diet that provides for healthy growth.*
- *Improve physiological and health tools for maximizing production and survival of eggs including staging of female pallid sturgeon to determine the optimal time for spawning.*
- *Determine the optimal size for stocking hatchery-reared pallid sturgeon.*
- Develop methods to maximize the efficacy of cryopreservation.
- Evaluate the contribution of hatchery-reared fish to wild populations.
- Define requirements for a sound and successful hatchery propagation program.
- Evaluate methods that can be used to improve egg quality in propagation programs.
- Learn and implement techniques used to successfully propagate other sturgeon species.
- Evaluate the efficacy, mortality, and side effects of anesthetics used in propagation programs.
- Evaluate whether pallid sturgeon will reproduce naturally in a hatchery environment and whether it can be used to increase the production of fish. In addition, natural reproduction in a hatchery can provide important information on the reproductive ecology of pallid sturgeon in the Missouri River system.
- Determine the best methods of cryopreservation and whether it can be a useful tool in propagation and recovery efforts.

Physiology and nutrition

Pallid sturgeon physiology and nutrition was a theme elucidated from the range of responses provided by the participants. Although nutrition included considerations for both cultured and wild fishes, most discussion focused on the diet and nutrition of fish in a hatchery environment. The highest priority research needs and knowledge gaps associated with physiology and nutrition included developing methods for assessment of maturation (e.g., ultrasound, collection of gonadal tissue), developing a better understanding of environmental factors related to maturation and egg development, reproductive success, and spawning migration, and developing diets that maximize survival and growth while minimizing nutritional pathologies (e.g., fatty liver, fin

curling). Many believe that fin curling is related to water quality; curling has been associated with the use of springs or wells. Additional knowledge gaps included those associated with life history characteristics (e.g., senescence, fecundity, spawning periodicity) and the role of habitat alterations on the diet and nutrition of wild pallid sturgeon.

- *Develop methods for determining maturation (e.g., collection of gonadal tissue, ultrasound).*
- *Develop a better understanding of the environmental factors influencing maturation, reproductive success (e.g., egg quality), and spawning migrations.*
- *Develop diets for pallid sturgeon that maximize survival and growth, and minimize fatty liver, fin curling, and other nutritional pathologies.*

Pallid sturgeon yearling. *Photo courtesy of U.S. Fish and Wildlife Service.*

- Evaluate the best methods for collecting gonadal tissues and blood samples, and conducting ultrasound.
- Evaluate methods for inducing egg development and spawning (e.g., hormonal implants).
- Determine the periodicity of spawning within the context of years, seasons, and days.
- Examine periodicity and factors influencing maturation of shovelnose sturgeon and compare to pallid sturgeon.
- Evaluate the age structure of pallid sturgeon populations.
- Determine the occurrence of senescence and age-specific changes in fecundity.
- Develop reagents (i.e., antibodies) for measuring hormonal levels in pallid sturgeon and determine whether there is cross-reactivity among sturgeon species.
- Examine the prevalence of fatty liver conditions in wild fish and determine the causes for high occurrence in hatchery-reared pallid sturgeon.
- Determine the effects of fatty liver on growth and survival of pallid sturgeon.
- Determine the cause (e.g., nutrient deficiency, water quality) and best methods for reducing fin curling in hatchery-reared pallid sturgeon.
- Conduct studies on the trophic ecology of juvenile pallid sturgeon.
- Evaluate the role of habitat alteration on the nutrition and growth of wild pallid sturgeon.

Fish health and disease

Evaluation and treatment of disease was identified as an important research need for pallid sturgeon recovery. Determining the extent and effects of iridovirus on pallid sturgeon was identified as a high-priority research need. Participants also identified the need to develop health baselines for larval, juvenile, and sexually-mature pallid sturgeon. However, these needs are overshadowed by the need for an accurate assay for iridovirus, understanding of the utility of immunocompetency for assessing fish health, and the best methods for sampling blood from pallid sturgeon. Additional comments regarding fish health and disease included a need for treatment evaluations (e.g., antibiotics, iodine treatments for eggs) and assessments on the role and transfer of contaminants as stressors to pallid sturgeon.

- *Determine the extent and effects of iridovirus on pallid sturgeon.*
- *Develop health baselines for reproductive adults, including an iridovirus assay (and effects of infections), use of antibiotics, immunocompetency, and the role and transfer of contaminants.*
- *Develop health baselines for larval and juvenile pallid sturgeon, including an iridovirus assay, use of antibiotics, immunocompetency, and the role of contaminants.*
- Develop a reliable method for isolating iridovirus and its effects on pallid sturgeon.
- Examine methods and recommendations for managing fish and populations infected with iridovirus.
- Evaluate the effects of iodine treatment of eggs on survival, hatch rates, and iridovirus.
- Develop techniques for evaluating the overall health of pallid sturgeon, particularly those in reproductive condition.
- Evaluate the role of contaminants on egg quality and hatching.
- Evaluate potential prey items for contaminants.
- Conduct a systematic review on the potential effects of contaminants and determine their presence and magnitude in the water and sediments.
- Evaluate the efficacy and side effects of different antibiotics on cultured pallid sturgeon.
- Evaluate methods (e.g., beta-glucans) to enhance the immune system of pallid sturgeon.

Natural reproduction and recruitment

The category of natural reproduction and recruitment reflected research needs related to spawning activities, growth, and survival of pallid sturgeon. Determining the availability and use of spawning habitats in the Missouri River and its major tributaries was identified as a high priority. Similarly, determining the environmental cues required to elicit spawning was also identified as a major gap in our knowledge of pallid sturgeon ecology. The last high-priority research need was identified as a need to identify the abiotic and biotic factors influencing growth and survival of larval pallid sturgeon. Additional research needs related to spawning included mechanisms by which fish identify conspecifics and whether a threshold number of individuals is necessary for successful spawning. Additional research needs associated with recruitment included determining the amount of habitat available for larvae, quantifying prey selection by larvae, identifying ontogenetic diet shifts, and developing sampling gears for larval and juvenile pallid sturgeon.

Pallid sturgeon. *Photo courtesy of U.S. Fish and Wildlife Service.*

- *Identify the availability and use of spawning habitats in the Missouri River and its tributaries.*
- *Determine the cues required to elicit spawning by pallid sturgeon including whether homing occurs.*
- *Determine factors influencing survival and growth (e.g., nutrition) of larval pallid sturgeon.*
- Determine the amount of habitat for larval pallid sturgeon, particularly downstream habitat for drifting fish.
- Determine whether the lack of recruitment in pallid sturgeon populations is a failure to successfully spawn or whether larvae and juvenile fail to grow and survive.
- Evaluate whether the lack of larval and small juvenile pallid sturgeon in most samples is due to our inability to adequately sample fish (e.g., gear efficiency) or a lack of fish.
- Determine whether downstream migration is an active or passive process.
- Determine prey selection and ontogenetic shifts in diet, particularly the switch to piscivory.
- Determine whether there is a “critical mass” required for successful spawning, recruitment, and genetic diversity in pallid sturgeon populations.

- Acquire the necessary parameter estimates to adequately model population dynamics of pallid sturgeon.
- Evaluate the best methods for sampling larval pallid sturgeon and determine their habitat use.
- Determine the mechanisms by which shovelnose sturgeon and pallid sturgeon locate and recognize each other, particularly with regard to spawning (e.g., pheromones).

Genetics and hybridization

Hybridization between pallid sturgeon and shovelnose sturgeon was viewed as a potential hindrance to recovery of pallid sturgeon in the Missouri River system, particularly in the lower river basin. Although hybridization may be a significant threat, many participants noted that our knowledge of the occurrence and frequency of hybridization is incomplete. Apparent hybrids may simply reflect natural morphological variation within sturgeon populations (phenotypic plasticity) rather than hybridization. Another important issue is the need to determine the genetic identity of broodstock for genetic marking of stocked fish and to examine genetic variability and status (e.g., gene flow, inbreeding and outbreeding depression) of wild fish. Consequently, obtaining baseline information on the occurrence, magnitude, and frequency of hybridization, as well as genetic information on broodstock and wild pallid sturgeon populations was identified as a high priority. With respect to hybridization, the group suggested that standardized methods for collecting tissue and measuring morphological characteristics are needed. Integrating genetic issues with current and future propagation issues was also identified as a high priority. Additional discussion of research needs focused on the relationship between stocking and hybridization issues (e.g., genetic swamping), and methodologies related to the documentation of hybridization (e.g., photographic records).

- *Obtain robust baseline data on hybridization, broodstock genetics, and genetics of wild fish throughout their distribution. Furthermore, methods of collecting genetic samples and morphological measurements should be standardized.*
- *Integrate policies, issues, and concerns related to genetics into current and future propagation activities.*
- Identify genetic baselines.
- Coordinate sampling and recording methods that enable for standardized collection of genetic and morphological information.
- Determine the occurrence of hybridization and the role of hybrids for preserving the pallid sturgeon phenotype.
- Evaluate whether hybridization can be overwhelmed by stocking genetically-pure pallid sturgeon.
- Evaluate whether an increased abundance of pallid sturgeon leads to increased prevalence of hybrids.
- Monitor movements and habitat use of hybrids to determine how they overlap with pallid sturgeon.

- Obtain samples from wild fishes to assess potential effects of inbreeding and outbreeding depression.
- Because natural recruitment of pallid sturgeon appears to be absent or extremely low, must remain cognizant of the potential genetic consequences of hatchery-reared fishes (i.e., swamping natural genetic diversity).
- Develop techniques and assess reliability of photographic vouchers.

Other issues

A variety of other research needs were identified that could not be categorized into any one major category. One such need was to determine which questions related to physiology, nutrition, disease, and endocrinology could be answered using hatchery-reared pallid sturgeon. Because shovelnose sturgeon and pallid sturgeon are closely related, the group also suggested that many basic questions could be answered using shovelnose sturgeon. The group also acknowledged that problems facing pallid sturgeon recovery differ among regions within their distribution. However, participants stated a need for improved communication and information exchange among regions.

- Determine which questions can be answered with regard to physiology, nutrition, disease, and endocrinology using hatchery-reared fish, and which questions can be answered using shovelnose sturgeon.
- Because different regions in the Missouri River basin face different problems, different approaches for research and management are likely. However, the system must be treated as a whole, thus elucidating the need for improved communication and information exchange among regions.

On the second day of the workshop, participants were asked to identify testable research hypotheses related to spawning, early life history characteristics, or other factors important to pallid sturgeon recovery. In particular, participants were encouraged to think about hypotheses related to experimental flow releases and the construction of shallow-water habitats. The other task was to list hypotheses, issues, or considerations that could be addressed over a two-year timeframe.

Experimental hypotheses related to flow manipulations and habitat improvement activities

Most hypotheses from the group focused on spawning cues and spawning habitat. Other hypotheses were more general and tended to focus on experimental flow releases rather than construction of shallow-water habitats.

- Shovelnose sturgeon respond similarly to pallid sturgeon with regard to environmental movement and spawning cues.
- Wild-spawning pallid sturgeon seek identifiable spawning habitats.
- Changes in the flow regime enhance pallid sturgeon spawning habitats.

- A rise in discharge and temperature during the spring is important for maturation (post-vitellogenesis to spawning).
- Flow, temperature, and turbidity are important to survival of age-0 pallid sturgeon.
- Changes in the flow regime enhance the availability and quality of nursery habitats.

Short-term considerations

The group identified a variety of research needs that could be addressed over a two-year timeframe. Major issues for consideration included genetics and hybridization, fish health (e.g., iridovirus, health baselines), hatchery production techniques, and cryopreservation.

- Determine whether the intermediate (morphologically) fish are truly hybrids.
- Determine whether currently defined management units are valid given the underlying genetic variation.
- Develop an iridovirus assay.
- Determine whether iridovirus is vertically transmissible.
- Determine whether iridovirus is equally prevalent in all management units.
- Determine the effects of iridovirus on the health of adult pallid sturgeon.
- Determine whether an iridovirus-recovered fish has the same survival success as an unaffected fish.
- Determine whether mucous cell and sensory cell counts are indicative of survival of pallid sturgeon.
- Determine baseline blood chemistry and hematology parameters for healthy wild and hatchery adults.
- Determine which blood chemistry and hematology parameters are diagnostic for broodstock health and survival.
- Determine whether commercial trout chow is optimal for various sturgeon life stages.
- Evaluate the role of diet and/or exercise in the incidence of fatty livers.
- Determine whether fatty liver is indicative of survival.
- Determine whether mortality of broodstock can be reduced by alternate methods of hormonal spawning induction and ovarian follicle collection.
- Determine whether current methods of ovarian follicle collection affect health of spawning female pallid sturgeon and egg quality.
- Determine which blood parameters can be indicative of response to ovarian follicle collection method.
- Evaluate whether large hatchery-reared pallid sturgeon have greater survival in the wild than smaller fish.

- Determine whether the current cryopreservation protocol is optimal for viability and fertilization.
- Determine whether cryopreservation can be used on a production scale.
- Determine the viability (i.e., longevity) of cryopreserved sperm.
- Evaluate the effects of power peaking on follicular quality and spawning performance.

Summary of Breakout Group II: Physical Habitat and Flow

Participants:

- Pat Braaten, Joyce Collins, Bill Gardner, Jo Grady, Dave Herzog, Robb Jacobson, Steve Lydick, Jim Parham, Mike Parsley, Wayne Stancill
- Jill Lovato (facilitator), Ann Boelter (recorder)

The first task assigned to the group was to identify two research needs or knowledge gaps related to the effects of physical habitat and flow on pallid sturgeon recovery. After each participant provided their input, research needs were categorized as belonging to one of four categories: (1) habitat formation, (2) habitat availability, (3) biological responses to habitat, and (4) other issues. "Habitat" was redefined by the group as the hydroscape, which includes both form (e.g., physical habitat) and flow. Group members believed it was necessary to make this distinction prior to discussion of research needs and knowledge gaps.

Upper Hamburg Bend of the Missouri River near Nebraska City, Nebraska. *Photo courtesy of Nebraska Game and Parks Commission.*

Habitat formation

The first major category focused on the processes and events related to the formation of habitat in the Missouri River basin (including tributary systems). One of the high priority research needs was to evaluate and better understand the processes associated with sediment transport that either create or eliminate habitat for pallid sturgeon. The group also identified a need to evaluate the interaction between flow and habitat improvement activities on the formation of pallid sturgeon habitat. Because habitat is important for all life history stages, participants stressed the importance of understanding habitat-forming or eliminating processes for all ontogenetic stages. Other high priority knowledge gaps focused on depositional habitats and their seral stage. In particular, the group stated a need to determine whether an optimal spatial and temporal mosaic of habitat exists and how habitats of different seral stages fit within that framework. Participants also stated a need to identify the spatial and temporal diversity of different seral stages in the system, how habitats are created and maintained, and their use by pallid sturgeon. Although the

group identified a list of high-priority research needs, an overriding research issue was the need to develop a framework and methodology for habitat classification that focuses on seral stages of depositional habitats. The classification system would allow researchers and managers to inventory habitats and monitor changes due to alterations in the hydroscape.

- *Evaluate the role of processes related to sediment transport that create and eliminate habitat for all life stages of pallid sturgeon.*
- *Determine whether there is an optimal mosaic of habitats, particularly those related to post-depositional habitats within the context of seral stages.*
- *Evaluate the role of habitat productivity, spatial and temporal diversity of habitats, and the benefits and function of different seral stages to each life stage of pallid sturgeon.*
- *Evaluate the interaction between flow and habitat improvement activities in creating or eliminating habitat for pallid sturgeon.*
- *Develop a framework and methodology for habitat classification that focuses on the seral stage of post-depositional habitats.*
- Determine the role of flow variability in the formation of habitat.
- Evaluate the ability of managers to recreate a natural hydrograph that includes not only flow, but also thermal characteristics and sediment transport.

Habitat availability

The second major category of research needs was similar to the first, but instead of focusing on the formation and maintenance of habitat, the second category focused on the availability of habitat for pallid sturgeon and other members of the fish assemblage. High-priority research needs identified by the group included determining the effects of flow on habitat characteristics and availability in the Missouri River basin. Specifically, participants suggested that the effects of flow should be identified with respect to magnitude, frequency, and duration. Similar to the first category (habitat formation), the group stressed a need to document the occurrence of different habitats in the system, which is contingent on the development of a habitat classification system. Additional research needs identified by the group focused on determining the habitat requirements of pallid sturgeon at different life history stages and the availability of habitat to each stage under different flow regimes.

- *Determine the effects of flow magnitude, frequency, and duration on habitat characteristics in the Missouri River system.*
- *Evaluate the effects of power peaking on habitat characteristics in the Missouri River system.*
- *Develop a habitat classification system for evaluating the effects of flow on habitat characteristics.*

- *Document the occurrence of different habitats in the system prior to the release of test flows from mainstem reservoirs.*
- Determine the availability of habitat for each life history stage under different flow regimes.

Pallid sturgeon. *Photo courtesy of U.S. Fish and Wildlife Service.*

Biological responses to habitat

Although understanding habitat dynamics is important, the response of pallid sturgeon is of critical importance for recovery efforts. As such, the group identified a multitude of research needs and knowledge gaps associated with the interaction of habitat and biological characteristics. A subset of the highest priority research needs focused on the requirements and selection of habitat by pallid sturgeon. These needs include determining traits of the hydroscape that promote recovery of pallid sturgeon, such as determining which habitats (i.e., microhabitat and macrohabitat) are limiting to all life history stages of pallid sturgeon. Another high-priority research need was the need to identify the minimum spatial unit and organizational structure of spatial units necessary for pallid sturgeon to complete their life cycle. Similarly, determining habitat use, home range size, interbasin movements, the influence of movement barriers, and habitats required for successful spawning was also identified as a high-priority research need. Examining the influence of habitat characteristics on the energy resources (e.g., prey availability) of pallid sturgeon in the Missouri River and its tributaries was also identified as a high priority. Additional research needs focused on various aspects of habitat use and selection, floodplain connectivity and energy transport, and the role of low flow conditions to pallid sturgeon.

- *Determine the factors that elicit pallid sturgeon spawning and the specific habitat used for spawning.*
- *Examine the role of habitat characteristics as related to the energy resources of pallid sturgeon.*
- *Determine the traits of a successful hydroscape (form + flow) for all life history stages of pallid sturgeon.*
- *Examine the seasonal habitat requirements and use of pallid sturgeon at all life history stages.*
- *Evaluate the selection of different habitats by pallid sturgeon, particularly with regard to microhabitat and macrohabitat characteristics.*
- *Determine which habitats are limiting for each life history stage and provide recommendations as to which habitats need to be constructed.*

- *Determine the minimum spatial unit and the organization of units required by pallid sturgeon to complete their life cycle.*
- *Describe habitat use, home ranges, and interbasin movement of pallid sturgeon.*
- *Evaluate the role of movement barriers (e.g., impoundments, low flow) on pallid sturgeon recovery.*
- Determine where and when pallid sturgeon spawning occurs in the Missouri River system.
- Determine habitat requirements and use of larval and juvenile pallid sturgeon.
- Determine the habitat factors that have resulted in a decline in pallid sturgeon, while at the same time have not had a detrimental influence on shovelnose sturgeon. In addition, determine whether habitat alterations have caused hybridization to occur more readily.
- Examine how prey production relates to habitat dynamics (e.g., flooding, backwater habitat) and the construction of shallow-water habitats.
- Determine the role of floodplain connectivity or lack thereof in the Missouri River system.
- Determine whether differences exist in population dynamics among river segments in response to different hydrographs and physical habitat characteristics.
- Determine the influence of low flow conditions on the ecology and recovery of pallid sturgeon.

Other issues

The last category associated with physical habitat and flow focused on the need to develop a long-term monitoring program for assessing both fish and habitat in the Missouri River and its tributaries. This need was viewed as an overriding issue necessary to document current conditions and evaluate future experimental manipulations of the system.

- Develop a robust, comprehensive, long-term program to monitor and assess both fish and habitat in the Missouri River and its tributaries.

On the second day of the workshop, participants were asked to identify testable research hypotheses related to spawning, early life history characteristics, or other factors important to pallid sturgeon recovery. In particular, participants were encouraged to think about hypotheses related to experimental flow releases and the construction of shallow-water habitats. The other task was to list hypotheses, issues, or considerations that could be addressed over a two-year timeframe.

Experimental hypotheses related to flow manipulations and habitat improvement activities

The habitat and flow group provided four sets of hypotheses that dealt with (1) flow experiments, (2) habitat improvement activities, (3) both flow and habitat manipulations, and (4) other issues. With respect to flow manipulations, participants reiterated the need to focus on the timing, magnitude, and duration of test flows relative to spawning and habitat use, as well as potential changes to the form of the channel. The group also suggested that flows might have physiological effects on spawning pallid sturgeon and that low flow conditions may be important for some life history stages of pallid sturgeon. With regard to habitat improvement activities, the primary focus of the group was on habitat diversity and increased availability of habitat for larval and juvenile pallid sturgeon. Hypotheses related to the synergistic effects of flow and habitat manipulations focused on habitat use and availability, and increased abundance of other members of the Missouri River fish assemblage. Increased abundance of other fishes was hypothesized to have a positive influence on growth and survival of juvenile and adult pallid sturgeon. Additional hypotheses tended to focus on the role of tributary systems for pallid sturgeon spawning, sediment dynamics, and energy transport (e.g., nutrient, prey species).

Pallid sturgeon. *Photo courtesy of MuseCo Publishing.*

With respect to flow manipulations

- A more naturalized hydrograph (magnitude, duration, timing) will elicit spawning by pallid sturgeon.
- A more naturalized hydrograph (magnitude, duration, timing) will result in pallid sturgeon using previously unutilized riverine habitats.
- A more naturalized flow regime will result in changes to pool, riffle, and run habitats.
- Test flows will substantially alter channel morphology in reaches downstream of Fort Peck Dam.
- Test flows downstream of Fort Peck and Gavins Point dams will affect habitat availability for pallid sturgeon, including spawning habitat.
- An early spring peak (first peak) in the hydrograph elicits a physiological response in pallid sturgeon and is sufficient to prepare spawning habitat.
- A low flow period will result in increased shallow-water habitat and will increase survival of juvenile pallid sturgeon.

With respect to construction of shallow-water habitats

- The current mosaic of habitats is available for pallid sturgeon to complete their life cycle in each segment of the Missouri River.
- Constructed shallow-water habitat will be used by larval and juvenile pallid sturgeon during low flow periods.

With respect to both flow manipulations and construction of shallow-water habitats

- Flow management and habitat construction activities will maintain riverine habitat thought to be important to pallid sturgeon and will elicit a positive biological response from pallid sturgeon and other benthic fishes (e.g., increased abundance, growth, recruitment, and survival).
- Test flows, physical habitat modification (e.g., wing dike removal), and tributary inputs downstream of Gavins Point Dam will act in concert to substantially alter channel morphology and will result in a biological response from pallid sturgeon.

Other considerations

- Pallid sturgeon use tributaries to spawn.
- Tributaries are an important source of sediment and nutrients to the Missouri River and contribute to high growth and survival of pallid sturgeon.

Short-term considerations

The last task of the group was to identify research needs and knowledge gaps that could be addressed over the next two years. The habitat group approached the task by listing a series of considerations and questions. Many of the considerations and questions were related to learning more about the ecology of pallid sturgeon (e.g., sampling eggs and larvae, using telemetry to locate spawning habitat, investigate biotic interactions), securing broodstock for propagation efforts, developing habitat classification protocols, and identifying the appropriate biological response measures in anticipation of flow experiments. Specific tasks included conducting larval drift tests where larvae are released and monitored at downstream habitats, and habitat modeling of reaches to predict potential changes in sediment transport and habitat dynamics associated with test flows and habitat improvement activities. The group also noted that experiments downstream of Fort Peck and Gavins Point dams differ in that releases from Fort Peck Dam do not include concurrent habitat improvement activities, whereas manipulations associated with Gavins Point Dam include both flow and habitat modifications.

- Various life history stages of native fishes in the Missouri River can serve as indicators of certain life history stages of pallid sturgeon.
- Use the fact that the experiments below Fort Peck and Gavins Point dams are different. In particular, experiments below Fort Peck Dam are related to flow,

whereas those downstream of Gavins Point Dam include flow and physical habitat manipulations.

- Develop habitat classification methodologies for use in the Missouri River and its tributaries.
- Conduct studies on pallid sturgeon movement and migration using telemetry.
- Conduct studies on movement and habitat use of other species (e.g., blue sucker, paddlefish, shovelnose sturgeon) that may provide insight as to the response of pallid sturgeon to experiments.
- Conduct intensive larval fish and age-0 pallid sturgeon sampling.
- Conduct studies on the food habitats of potential piscivores, particularly nonnative species.
- Continue to aid the USFWS in locating and securing broodstock.
- Conduct larval drift test where larval pallid sturgeon are released and then monitored downstream.
- Consider temperature and turbidity characteristics when designing and implementing experimental flow releases.
- Consider which life stages are most appropriate for detecting biological responses to experimental flow releases and physical habitat modifications.
- The timing and duration of test flows should encompass the time of egg maturation (i.e., pre-spawn).
- Consider flexibility in flow releases associated with uncontrollable factors, such as the occurrence of short, warm winters.
- Model reaches to examine the occurrence and magnitude of potential sediment transport following flow releases.
- Identify and sample potential spawning sites over the next two years.

Summary of Breakout Group III: Life History Characteristics, Growth, and Population Assessment

Participants:

- Nancy Auer, Doug Carlson, Chris Guy, Jack Killgore, Boyd Kynard, Gerald Mestl, Vaughn Paragamian, Ed Peters, Bobby Reed, Mark Wildhaber
- Nicole Korfanta (facilitator), Mike Quist (recorder)

Participants were asked to identify two knowledge gaps or research needs associated with life history characteristics, growth, and population assessment as they relate to pallid sturgeon recovery efforts. Research needs were then categorized into one of

seven broad categories: (1) nutrition, (2) movement and migration, (3) population assessment, (4) habitat, (5) methodology and logistic considerations, (6) contaminants, and (7) biotic interactions. Unlike the first group, research needs related to nutrition focused on energy resources in a natural environment.

Nutrition

The first major category focused on nutrition as it relates to growth and survival of pallid sturgeon in the Missouri River and its tributaries. High priority research needs included determining the food habits, describing ontogenetic dietary shifts, and determining whether growth and survival of pallid sturgeon are limited by prey resources. Participants also identified that elucidating the role of nutrient and energy flow in the system is a high priority. In particular, the group suggested that determining the relationship between organic debris (e.g., large woody debris) and predator-prey dynamics was a high source of uncertainty in recovery efforts. The group also suggested that the role of reservoirs as nutrient sinks is an important knowledge gap. Although not identified as one of the high priority needs, participants stated that bioenergetic modeling might be insightful. Many of the necessary inputs required for the model will be obtained by focusing on other research needs (e.g., food habits, growth).

- *Determine whether prey resources are a factor limiting growth and survival of pallid sturgeon.*
- *Describe food habitats and determine ontogenetic diet shifts of pallid sturgeon.*
- *Determine the relationship between organic debris (e.g., large woody debris) and predator-prey dynamics.*
- *Examine the role of reservoirs as nutrient sinks and their subsequent effects on pallid sturgeon and associated fish assemblages.*
- *Examine the role of energy transport in the Missouri River system as it relates to pallid sturgeon growth and survival.*
- Obtain estimates on the identity and quality (e.g., caloric density) of prey items for pallid sturgeon that can be used as input variables for bioenergetics models.

Movement and migration

The group identified several research needs associated with movement of pallid sturgeon. Specifically, determining environmental cues necessary to elicit a spawning migration was identified as a priority. Participants also stated that determining movement patterns of juvenile pallid sturgeon is a high priority. An additional research need was to determine the movement of pallid sturgeon immediately after hatching.

- *Determine the cues for pallid sturgeon movement, particularly with in the context of spawning migrations.*
- *Define upstream and downstream movement patterns of each life history stage.*
- Determine the fate of juvenile pallid sturgeon after hatching.

Population assessment

Participants identified a broad category focused on population or stock assessment. Long-term monitoring of pallid sturgeon population dynamics and population size was identified as a high-priority research need. Nested within population dynamics is a need to obtain information on growth, recruitment (including stocking success), and mortality. Many knowledge gaps were related to other research needs already identified (e.g., reliable growth estimates, stocking success, fishing mortality).

Drifting nets. *Photo courtesy of U.S. Fish and Wildlife Service.*

- *Conduct long-term monitoring of pallid sturgeon population dynamics (i.e., abundance, recruitment, stocking success) and the associated fish assemblage.*
- *Obtain robust and reliable estimates of population size (e.g., using capture-recapture methods).*
- Evaluate the contribution of hatchery-reared pallid sturgeon to the population.
- Obtain validated length-age relationships.
- Evaluate the effects of commercial harvest of shovelnose sturgeon and recreational angling on pallid sturgeon recovery.
- Determine the occurrence and extent of hybridization, and the life history characteristics of hybrids.
- Define the population characteristics of a self-sustaining population of pallid sturgeon in the Missouri River system.
- Obtain input variables for developing a bioenergetics model and conducting population viability analyses (PVA).

Habitat

High-priority research needs related to habitat included the evaluation of locations and specific microhabitat characteristics associated with egg deposition. The effect of physical habitat improvement activities on all life history stages of pallid sturgeon was also considered a high priority. An additional research need focused on the habitat alterations that have occurred to promote hybridization in the lower Missouri River system. The group also discussed the utility of identifying locations in the Missouri River drainage where habitat conditions are relatively natural so that baseline information on habitat use and selection can be studied.

- *Evaluate the environmental factors affecting spawning.*

- *Determine the specific locations and microhabitat features associated with spawning.*
- *Evaluate the use of recent physical habitat modifications (e.g., wing dike removal) by all life history stages of pallid sturgeon.*
- Determine the specific habitat alterations that have enabled hybridization.
- Prioritize the location and extent of relatively natural areas that can be used to provide baseline knowledge on habitat use and selection by pallid sturgeon.

Methodology and logistic considerations

An overriding research need or task identified by the group was the need to develop and implement standardized protocols for sampling and monitoring all life history stages of pallid sturgeon. Additional research needs associated with methodology included the identification of acceptable detection limits for monitoring, development of field methods for determining the sex and reproductive stage of fish, and evaluation of methods for reducing handling stress. In addition, the group stated a need to identify whether other species (e.g., shovelnose sturgeon, catostomids) could be used as surrogates for pallid sturgeon and how they might be used to help locate pallid sturgeon spawning and rearing habitats.

- *Develop standardized protocols (spatially and temporally) for sampling and monitoring all life history stages of pallid sturgeon.*
- Evaluate the effort required to monitor populations and define an acceptable detection limit.
- Develop field methods for determining the sex and reproductive stage of pallid sturgeon.
- Evaluate methods to minimize handling stress.
- Determine whether an appropriate surrogate exists to answer questions related to pallid sturgeon ecology.

Contaminants

The effect of contaminants was identified as a knowledge gap associated with pallid sturgeon recovery. Specifically, participants broadly identified a need to evaluate the role of contaminants on growth, survival, and reproduction of pallid sturgeon. The group also discussed a need to identify the response (movement and habitat use) of pallid sturgeon to abrupt changes in water chemistry that result from natural (e.g., runoff) or anthropogenic disturbances (e.g., water treatment effluent).

- *Evaluate the effects of contaminants on growth, survival, and reproduction of pallid sturgeon.*
- *Evaluate the response of pallid sturgeon (e.g., movement) to abrupt changes in water chemistry.*

Biotic interactions

The last major category identified by the group was the influence of biotic interactions on growth and survival of pallid sturgeon. The highest priority research need was to identify the effect of predators and competitors on early life history stages of pallid sturgeon. Additional questions related to biotic interactions focused on the effects of historic habitat alteration to fish assemblage structure and the need to determine whether other species in the system will benefit or be harmed by efforts to restore pallid sturgeon.

Missouri River near Bismarck, North Dakota. *Photo courtesy of U.S. Geological Survey.*

- *Identify the effects of predators and competitors on the early life history stages of pallid sturgeon (e.g., egg and larval predators, larval competitors).*
- Determine which species will benefit and those that might be harmed by pallid sturgeon management and restoration activities.
- Evaluate how fish assemblage structure and function have been altered in the Missouri River system as a result of impoundment and channelization.

On the second day of the workshop, participants were asked to identify testable research hypotheses related to spawning, early life history characteristics, or other factors important to pallid sturgeon recovery. In particular, participants were encouraged to think about hypotheses related to experimental flow releases and the construction of shallow-water habitats. The other task was to list hypotheses, issues, or considerations that could be addressed over a two-year timeframe.

Experimental hypotheses related to flow manipulations and habitat improvement activities

Similar to the other two groups, the group was asked to provide specific research hypotheses related to flow and habitat manipulations. Rather than limit research hypotheses to only flow and habitat manipulations, the group identified broad research hypotheses that included dominant factors likely influencing different life history events of pallid sturgeon. The group identified three primary subsets of hypotheses. The first set of hypotheses focused on characteristics that might influence spawning migrations and the selection of sites for egg deposition. The next set of hypotheses focused on growth and survival of pallid sturgeon at each step in their ontogeny (egg to hatch, free embryo, larvae to juvenile, age 0 to age 1, and age 1 to age-at-maturity). While many of the influential characteristics related to growth and survival are similar among life history stages (e.g., water temperature and velocity), some factors are not relevant to early life history stages. For example, food availability is not important for eggs and free

embryos and exploitation is only important for fish large enough to be captured. The last group of hypotheses focused on population assessment and methodologies associated with monitoring trends in pallid sturgeon populations.

- Key factors cueing the spawning migration of pallid sturgeon include discharge, photoperiod, water temperature, and water quality.
- Key factors influencing the selection of spawning sites and areas for egg deposition are substrate characteristics, depth, water velocity, turbulence, water temperature, moon phase, and discharge patterns.
- Survival and successful hatching of pallid sturgeon eggs (after deposition) are related to sediment dynamics and substrate characteristics (e.g., size, embeddedness, interstitial spaces), water temperature, water velocity, bedload movement, predation, and the amount of contaminants in the sediment.
- Survival and growth of free-embryo pallid sturgeon are related to predation, discharge, water temperature, hydraulic patterns and diversity, contaminants, and entrainment (e.g., towboats, irrigation diversions, power stations).
- Survival and growth of age-0 larval and juvenile pallid sturgeon are related to predation and competition, discharge, water temperature, hydraulic patterns and diversity, food availability and selection, habitat availability and selection (including habitat diversity), contaminants, and entrainment.
- Survival and growth of pallid sturgeon from age 0 to age 1 are related to predation and competition, discharge, water temperature, hydraulic patterns and diversity, food availability and selection, habitat availability and selection (including habitat diversity), contaminants, and entrainment.
- Survival and growth of pallid sturgeon from age 1 to age-at-maturity are related to predation and competition, discharge, water temperature, hydraulic patterns and diversity, food availability and selection, habitat availability and selection (including habitat diversity), contaminants, entrainment, and exploitation.
- Trends in presence-absence, population density, age structure, growth, mortality, and recruitment are similar among regions and do not vary through time. Although not a research hypothesis, an overriding, concurrent need associated with obtaining stock assessment parameter estimates is the need for standardized, long-term monitoring methodologies and protocols.

Short-term considerations

The group was then asked to provide a list of research needs that can be addressed during the next two years, as well as considerations associated with test flows and habitat improvement activities. The Habitat and Flow group listed their research hypotheses with respect to flow manipulations and habitat improvement activities. This group took a similar approach, but instead of using the framework of flow versus

habitat for categorizing research hypotheses, the group used this framework to list short-term research needs and considerations. With respect to flow experiments, participants agreed that thermal characteristics should be a major consideration when implementing flow releases rather than a calendar date. The group also suggested that duration and magnitude of test flows should be an important consideration. Specific research recommendations included conducting experiments on the Fort Randall reach (between Fort Randall Dam and Lewis and Clark Lake) because some research has already been conducted on pallid sturgeon and because water temperatures can be manipulated. From an experimental design perspective, the group stated that manipulating temperature, discharge, or both could be extremely useful. An additional research idea that could be addressed over the short term is to tag pre-spawning pallid sturgeon and identify spawning locations. Once spawning areas or concentrations of fish are identified, biologists can collect new individuals for study and determine reproductive stage. The group also recommended sampling of eggs and larvae near probable spawning areas. With respect to the construction of shallow-water habitats, the group suggested a need for monitoring the use or disuse of habitats by pallid sturgeon. The group also recommended monitoring the entire fish assemblage on constructed habitats because, even if pallid sturgeon are not sampled, monitoring other fishes might show a biological response.

Fort Randall Dam on the Missouri River, South Dakota. Photo courtesy of U.S. Geological Survey.

With respect to flow manipulations

- Consider temperature as the decision for the timing of flow releases rather than calendar dates.
- Consider duration and magnitude of the experimental releases in conjunction with timing.
- Conduct experiments on the reach between Fort Randall Dam and Lewis and Clark Lake (Fort Randall reach) for several reasons: (1) pallid sturgeon are relatively abundant in the reach and are currently being studied (pre-treatment information); and (2) thermal characteristics of released water can be manipulated in the reach allowing research to separate the effects of flow and temperature on pallid sturgeon responses. If pallid sturgeon are unavailable for study, shovelnose sturgeon can be substituted, which may provide important insight regarding the potential response of pallid sturgeon to discharge and temperature.

- Use telemetry to monitor movement and spawning of pallid sturgeon by tagging pre-spawn fish (pallid sturgeon and shovelnose sturgeon) and mapping available and used habitat.
- Identify areas where pallid sturgeon congregate during the spawning season (e.g., using telemetry techniques). Sampling these areas allows additional fish to be captured and implanted with radio-tags and allows reproductive stage to be determined.
- If probable spawning areas are identified, sample eggs and larvae using D-frame nets similar to those used for other sturgeon species.

With respect to construction of shallow-water habitats

- Evaluate the utility of instream flow models (e.g., instream flow incremental methodology) for assessing habitat availability.
- Evaluate whether pallid sturgeon select constructed shallow-water habitats using laboratory experiments.
- Evaluate the presence or absence of juvenile pallid sturgeon in constructed shallow-water habitats.
- Evaluate the response of fish assemblages (presence-absence, abundance, assemblage structure) to constructed shallow-water habitats.

Appendix D— Summary of Plenary Session Discussions

Day 1 (Plenary Session-Group Discussion of Breakout Reports)

The purpose of the group discussion was to provide each breakout group with an opportunity to share their ideas with all of the participants. Each group identified a reporter who presented the important ideas discussed during the breakout session, including high priority research needs and sources of uncertainty related to each topic. Following a brief presentation, workshop participants were allowed to ask questions, provide comments, and discuss important aspects that might have been missed by the breakout group. Below is a summary of comments raised during the session and corresponding points of discussion. Rather than reiterate each of the research needs identified by the breakout groups (see Appendix C), only major comments and areas of discussion will be presented.

Breakout Group I (Reproduction, Propagation, and Genetics)

The group reported the major research needs and knowledge gaps associated with hatchery propagation, physiology and nutrition, fish health and disease, natural reproduction and recruitment, genetics and hybridization, and other research needs that did not clearly fit in a major category. Following the presentation of research needs and issues, participants asked numerous questions for clarification and raised additional ideas for consideration. Many questions focused on whether the breakout group discussed issues related to the time of stocking, size of stocked fish (including the use of multiple sizes), and locations for stocking. Members of the breakout group indicated that they had discussed factors related to stocking success and that evaluating the best methods for stocking pallid sturgeon was identified as a high priority. Discussion also focused on alternatives to present culture techniques. In particular, experts stated that natural spawning under controlled conditions in the hatchery might be worth pursuing since there has been some success with shortnose sturgeon. Members of the group stated that investigating the potential for natural reproduction in a hatchery environment and learning from the experience of culturists dealing with other sturgeon species was an important focus of discussion during the breakout session. Participants also stressed the urgency to better understand the effects of iridovirus because it currently influences decisions on stocking and the management of hatcheries. The consensus was that iridovirus is indeed a potentially serious concern that warrants increased attention.

Breakout Group II (Physical Habitat and Flow)

The group reported the major research needs, knowledge gaps, and uncertainties associated with the formation of habitat, habitat availability, biological responses to habitat, and other issues that did not clearly pertain to the other categories. Following the presentation of research needs, participants raised several questions and provided additional comments on habitat-related issues. Most questions and comments were related to potential flow experiments and habitat improvement activities. Participants stressed that regardless of the specific experiment or manipulation, identifying the life history stage to benefit from the actions is critical. After the life stage is identified, appropriate experiments, assessment techniques, response measures, and other population metrics can then be developed within that framework. With respect to biological response measures, participants questioned whether densities of pallid sturgeon were the best measure of response. Rather, other species (e.g., shovelnose sturgeon, cyprinids, catostomids) might be useful indicators of a positive or negative response to management activities given the current rarity of pallid sturgeon in the basin. Experts also stated that researchers investigating extremely rare white sturgeon populations are able to sample eggs and larvae. Thus, the lack of early life history stages in samples from the Missouri River might be due to inefficient sampling gears or because the wrong habitats are being sampled. Members from the breakout group acknowledged these concerns and stated that recent low water characteristics in the Missouri River has enabled researchers to map the location of hard substrates. Identifying the location and spatial extent of hard substrates might lead others to novel and potentially important sampling areas. Comments also focused on differences in focal research areas throughout the basin. Specifically, participants noted that researchers and managers in the upper basin may have more interest in test flows, whereas biologists in the lower basin are probably most interested in evaluating the effects of physical habitat modification efforts. Lastly, participants noted that although temperature and turbidity have been shown to be important for other sturgeon species, they were not presented in detail. Members of the breakout group indicated that temperature and turbidity were discussed as one component of the hydroscape and that understanding sediment transport dynamics (including turbidity) was a high priority.

Breakout Group III (Life History Characteristics, Growth, and Population Assessment)

The group reported important research needs, knowledge gaps, and uncertainties related to nutrition, movement and migration, population assessment, habitat characteristics, methodology and logistic considerations, contaminants, and biotic interactions. Following the presentation, participants asked whether standardization of telemetry gear was considered by the breakout group. The group stated that the concern was implied in the need to standardize research and monitoring efforts in the basin. However, standardization of radio-tag frequencies was not specifically discussed because it was not perceived as a specific research question. One of the research needs identified by the breakout group focused on hybridization, which prompted discussion on hybrids in the basin. A point was made that we need to remember that a clear understanding of the occurrence and frequency of hybridization in the system has not been eluci-

dated. Although many "intermediates" are probably hybrids, we should temper discussion of hybrids until more research is conducted. Many of the research needs identified by the breakout group focused on habitat associations and movement related to spawning and early life history stages. Discussions regarding habitat use and movement suggested that we should focus on the habitats that promote growth, survival, and recruitment instead of habitats where fish are simply located. However, many noted that attaining this information is extremely difficult given the status of pallid sturgeon and because the Missouri River is a highly disturbed environment. A point was also made that the focus of this breakout group was different from the other groups in that they focused on measures of "fitness" (i.e., growth, recruitment, mortality). Thus, the issue of where fish are located relative to optimal habitats is extremely important to consider because where fish are located may have little application to their fitness measures and long-term persistence. However, documenting growth and survival in different habitats should help to elucidate optimal habitats.

Injecting elastomer tag. *Photo courtesy of U.S. Fish and Wildlife Service.*

Following discussion among the invited technical experts, observers were asked to present their observations and comments related to the ideas discussed during the breakout sessions and the group discussion. Only two observers commented and both provided important insight and research needs related to pallid sturgeon recovery. The first observer noted that the effects of aeolian processes on habitat (e.g., sand bars) should be considered. The observer also suggested that the role of tributaries needs to be addressed. In particular, determining the contribution of tributaries as spawning habitat and sources of sediment, nutrients, and contaminants should be a high priority. The other observer expressed concern that there has been little focus on the role of predation by introduced species on pallid sturgeon, particularly in upper portion of the Missouri River basin. Members from breakout group II noted that biotic interactions were addressed in their breakout session. Nonetheless, all agreed that determining the influence of predation and competition should be a high priority.

Day 1 (Facilitated Open Discussion)

The original intent of the open discussion was to identify issues that transcended all of the breakout groups and to outline the focus of additional breakout sessions (on Day 2). Although several cross-cutting issues were apparent (see bulleted items below), the issues were very similar to the topics already discussed. Therefore, discussion focused on issues that could be addressed within the next two years. Primary research needs included a need to conduct laboratory studies on basic life history characteristics (e.g.,

physiology) of pallid sturgeon and to develop "white papers." One white paper that was immediately identified by participants was a review of the current state of knowledge regarding pallid sturgeon. Additional potential white papers included a review of pallid sturgeon genetics and the development of a conceptual or computational model to be used for examining the complexities of the Missouri River system. Observers reiterated a need to focus on tributaries and biotic interactions. In addition, an important comment was made that regardless of the next step in the process, researchers, managers, and stakeholders must consider the cost, consensus, and opportunities associated with all actions in the Missouri River basin.

Cross-cutting issues [note: these are some of the issues identified during one discussion session but this list is not meant to be all inclusive]

- Importance of restoring the natural hydrograph
- Occurrence, causes, and effects of hybridization
- Understanding the suite of environmental stressors that are affecting different life stages, populations, and communities
- Characterize habitat requirements of the various life stages
- Develop an aquatic habitat classification system that will be tied to the life stages
- Genetic and morphological variation on a range-wide basis
- Effects of hydropower peaking operations
- Identify limits to survival in the life history
- Characterize the historical and contemporary hydroscape
- Determining early life history requisites
- Characterize larval drift
- Effects of suspended solids on egg/larval stages
- Identify spawning locations and characteristics
    - Determine the feasibility of building new spawning habitats
- Identify rearing locations and characteristics
    - Determine the feasibility of building new rearing habitats
- Spawning and spawning migration cues
- Evaluation of environmental factors that affect spawning
- Standardization of data collection
- What are the short-term objectives/opportunities?
- Ways to monitor signs of recruitment

Day 2 (Plenary Session-Group Discussion of Breakout Reports)

The purpose of the group discussion was to provide breakout groups with an opportunity to share their ideas with other workshop participants. Similar to group discussions on the first day, groups identified a reporter who presented results of the morning breakout session. In contrast to the first day, breakout sessions focused on testable research hypotheses related to flow and habitat manipulations and research needs that could be addressed over a two-year timeframe. Below is a summary of the comments raised during the session and corresponding points of discussion. Rather than reiterate each of the hypotheses and short-term research needs identified by the breakout groups (see Appendix C), only major comments and areas of discussion will be presented.

Breakout Group I (Reproduction, Propagation, and Genetics)

After presenting research hypotheses and short-term research needs, discussion revolved around issues related to stocking pallid sturgeon. The first issue raised by participants focused on using larval pallid sturgeon in population augmentation efforts. While some experts questioned whether stocking larval pallid sturgeon would be successful, others suggested that imprinting by larval fish might be extremely important for long-term persistence of pallid sturgeon in the basin. Participants noted that recent research has provided an indication of imprinting and spawning-site fidelity with other sturgeon species. An early study on pallid sturgeon physiology and evidence from larval sturgeon morphology (e.g., highly-developed olfactory bulbs) indicates that we should consider imprinting of larvae. Specifically, determining whether imprinting occurs, how it occurs, and at what age fish imprint were all identified as important research questions. Participants also raised questions about stocking success and whether hatchery-reared pallid sturgeon can be chemically marked (e.g., oxytetracycline). This comment lead to a long discussion regarding the need for genetic marking. Experts reiterated a need to describe the underlying genetic structure of wild fish and to determine the genetics of broodstock. Genetics experts noted that the tools required to conduct the analyses are available and all that is needed is funding and samples.

Breakout Group II (Physical Habitat and Flow)

The group reported several testable hypotheses related to physical habitat and flow manipulations, as well as short-term research needs. Major discussion topics following the report focused on spawning habitat characteristics and flow considerations. A question raised by participants was related to the opportunities associated with the Yellowstone River and upper Missouri River. Experts suggested that recent research in the Yellowstone and Missouri rivers below Fort Peck indicates that most opportunities for improvement occur in the Missouri River. Larval pallid sturgeon produced in the Yellowstone River have only a short distance to drift before entering Lake Sakakawea. However, if fish would spawn in the Missouri River, they could have up to 300 km to drift before entering the reservoir. The primary problem is that most adult pallid sturgeon moving up the Missouri River enter the Yellowstone River rather than the Missouri River. Given discussion regarding imprinting, participants thought imprinting larval pallid sturgeon in the Missouri River below Fort Peck might be an important

research need. Because the information discussed regarding dynamics of the Yellowstone and upper Missouri rivers was new to most participants, and other similar idiosyncratic stories likely exist throughout the basin, participants suggested a need to thoroughly summarize information on pallid sturgeon ecology and current research. Such an effort would be extremely useful for identifying the current state of knowledge and would help to identify research opportunities related to pallid sturgeon ecology and recovery efforts. The other major focal area for discussion revolved around the dynamics and availability of spawning habitats. Participants noted that although gravel and other rocky substrates may be present in the system, patches of suitable habitat may be ephemeral, highly dynamic, or unsuitable for spawning (e.g., embeddedness). Habitat experts stated that efforts are currently being conducted to map hard substrates in the lower Missouri River. Because tributaries may also be important for pallid sturgeon, suggestions were made to include tributaries in habitat mapping efforts. However, many argued that we should first determine whether fish use tributaries. If pallid sturgeon use tributaries, efforts should then be extended to tributary systems. Lastly, participants acknowledged that recent efforts focusing on the Platte River (e.g., a Biological Opinion) should be coordinated with those efforts in the mainstem Missouri River.

Breakout Group III (Life History Characteristics, Growth, and Population Assessment)

After presenting research hypotheses and short-term research needs, a long discussion ensued regarding the Fort Randall reach. The Fort Randall reach is located between Fort Randall Dam and Lewis and Clark Lake. Pallid sturgeon are present in the reach and have been studied during the last few years using telemetry. The unique aspect of the reach is that both temperature and flow can be manipulated. Many researches expressed interest in the idea because the effects of temperature and discharge can be separated and preliminary information on pallid sturgeon is available. Similar benefits are unavailable in other portions of the system. While discussing the Fort Randall reach, participants reiterated the idea that habitat use may not be indicative of optimal habitat. Results from the ongoing Fort Randall reach study have shown that prey items consumed by pallid sturgeon are not concordant with their habitat use. Recent research suggests similar mechanisms for white sturgeon where riparian habitats appear to be important for white sturgeon growth and survival, even though white sturgeon are never found in riparian habitats. Consequently, the group agreed that there is a need to better understand the role of different habitats on energy transport and ecosystem function. The focus of the discussion shifted to habitat use and availability within the context of constructed habitats in the lower Missouri River. Specifically, participants warned that juvenile pallid sturgeon may not use the constructed habitat. In response, many argued that lack of pallid sturgeon in constructed habitats is extremely important information and that monitoring the response of other fishes to habitat modifications should be a high priority. To help aid in the design of constructed habitats, participants suggested using laboratory studies to examine selection of different microhabitats (e.g., depth, water velocity, substrate composition). Additional short discussions reiterated a need to mark stocked fish and to examine the role of contaminants on different life history stages of pallid sturgeon.

Appendix E— Summary of Public Information Exchange

Participants:

Alan Allert, Robert Bacon, Bill Beacom, Jim Berkley, Pat Braaten, Sue Camp, Roger Collins, David Galat, Ed Heist, Harold Hommes, Robb Jacobson, Don Jorgensen, Ann Korschgen, Carl Korschgen, Steve Krentz, Bernie Kuhajda, Doug Latka, Sam Luoma, Mike Mac, Mike Oetker, Jim Parham, Mike Parsley, Ed Peters, Nick Stas, Cindy Williams, Rob Wood

The purpose of the public information exchange was to inform stakeholders of what transpired during the workshop. Despite widespread advertisement of the exchange, all attendees were present for at least a portion of the workshop. However, the composition of attendees allowed focused discussion of specific issues related to the process of pallid sturgeon recovery and management of the Missouri River.

The first major issue that was discussed focused on the risks associated with flow releases. In particular, many attendees were concerned about the risks associated with flooding that might occur when high runoff from stochastic rainfall events is added to increased flows for pallid sturgeon. Federal managers associated with the flow tests indicated that part of the process for implementing flow manipulations includes a risk analysis. However, many argued that the risk analyses are limited in that there are defined bounds to the model and that the analysis often ignores specific areas that might have a higher risk than other areas in the system. During the course of the next two years, additional analyses will be conducted to address these concerns. In addition to high flows, the risk of low flows was also discussed because minimum flows are required for water withdrawals associated with agriculture, municipalities, and power plants. Attendees also discussed the potential for negative socioeconomic impacts resulting from flow releases. Although economic analyses have been conducted by federal agencies responsible for water management, many participants argued that the models are inadequate. Specific industries thought to likely experience a negative economic impact due to flow manipulations included the navigation, agriculture, energy, and recreation industries. One participant noted that the navigation industry has already suffered substantial economic losses. If flooding occurs, economic impacts could be drastic given the infrastructure and number of people who reside along the

Missouri River near Ft. Benton, Montana. *Photo courtesy of U.S. Geological Survey.*

Missouri River. Attendees reiterated that irrigators, municipalities, and the energy industry could suffer substantial economic losses without mitigation of low flows. Regardless of how the test flows proceed, stakeholders associated with the system need to be informed long before any actions are taken. Informing stakeholders will enable them to plan accordingly for potential impacts resulting from flow experiments.

The next body of discussion focused on technical aspects of pallid sturgeon recovery. First, the effects of biotic interactions on pallid sturgeon were reiterated. Several attendees argued that few members of the public would believe that predators do not influence pallid sturgeon survival. Although biotic interactions were discussed during the workshop, research should specifically address questions related to predation. Stakeholders were assured that biotic interactions were taken into consideration during the workshop and that predation is one of many potential influences on juvenile pallid sturgeon. Another technical comment focused on the need to study channel incision and reduced habitat diversity of the Missouri River resulting from reduced sediment transport. Many attendees questioned whether increased flows would be enough to alter habitat given reduced sediment inputs and the confined channel in the lower river. Active construction of habitats and concurrent flow experiments were viewed as necessary activities to elicit a response in riverine habitats and pallid sturgeon. Attendees agreed that research ideas discussed during the workshop will be useful for examining changes in the form and function of habitat in the system. One attendee stated that the workshop identified the most important technical issues in the basin and established a set of good research hypotheses. However, the attendee questioned why it has taken researchers and managers so long to conduct a workshop, even though many of the problems have been known for over 20 years. Participants stated that we need to focus on the future of the river and its biota instead of the past. Many argued that we are doing the best we can given the constraints and issues related to management of the river.

A large portion of the information exchange was devoted to discussing whether the process associated with pallid sturgeon recovery and the workshop were transparent to the public and how agencies can increase participation by stakeholders. Despite the lack of stakeholders at the workshop, all attendees that were not invited technical experts agreed that the process had been open and transparent. Moreover, attendees were thankful to the scientists for listening to their ideas and incorporating those ideas into discussions at the workshop. Lack of participation at the workshop by stakeholders was

viewed to be a result of other commitments (e.g., job constraints), rather than a lack of interest. One suggestion to increase public participation was to hold more local meetings so that constraints associated with travel would not be an issue. Attendees also suggested that stakeholders be allowed an opportunity to comment on publications associated with management of the river and research activities. Based on these discussions, most attendees agreed that a transparent process with open and sincere communication among all entities is needed and that the workshop was a step in the right direction. Most attendees commented that the momentum for an open process should be maintained and that meetings among researchers, managers, and stakeholders should occur on a more frequent basis. One attendee stressed the need for more communication, otherwise suspicions arise among researchers, managers, and the public. Several researchers also suggested that stakeholders need to get more involved in the process. Each entity (i.e., stakeholders, researchers, managers) has a specific role and it is the responsibility of each entity to fulfill that role. For example, if scientists are supposed to remain objective, then the job of advocacy lies in the realm of stakeholders. Understanding the roles of all interested parties will be critical for recovering pallid sturgeon and managing the Missouri River.

Lastly, attendees commented that we are embarking on a new way to manage the Missouri River system. The key to successful management of the river and recovery of pallid sturgeon is to maintain frequent and open discussions among researchers, managers, stakeholders, and policy-makers in the basin. Attendees agreed that the process that has emerged (using the workshop as an example) is just as important as the technical issues. Moreover, attendees stated that we need to avoid making a fatal error in the process so that accumulated accomplishments are not nullified. The key to avoiding a fatal error is open communication among all parties involved in management of the Missouri River and its resources.

Appendix F— Additional Ideas Contributed by Reviewers

The following techniques, ideas, or questions were contributed by reviewers for the research needs covered at the workshop.

Life history stages and events

- Develop biologically-delivered sensors that log biologically significant behavioral events, including spawning.
- Consider developing passive sampling devices (chemical or remote sensing technology) to detect sturgeon and sturgeon spawning activity.
- Is there a density-dependent influence both on gamete maturation and spawning in sturgeon?
- Develop pheromone-based technology to explore sampling techniques to collect broodstock and determine presence or absence of spawning adults
- The presence of adult shortnose sturgeon at the same site every year does not necessarily indicate imprinting or homing, but it does indicate site fidelity. This could be explained both by imprinting and/or by a high degree of preference for discrete habitat patches.

Habitat formation and maintenance

- Need a range-wide comparative assessment to determine a template for the appropriate habitat elements for pallid sturgeon. Is the best physical habitat today the same as what was historically available?
- Need to examine historical hydrographs for the species range including areas outside the Missouri River to help determine the hydrograph that the species requires.
- Seasonal tributary flow is an important issue. In addition to contributing to mainstem discharge, spawning cues for a large river fish can just as easily come from a tributary as from the mainstem.

- Habitat improvement, stability, and productivity can be inferred from invertebrate studies.
- Need to examine upstream passage of adults and downstream escapement of age-0 and juvenile sturgeon at the dams. What engineering modifications would be required to allow passage? Also need to prevent passage of aquatic nuisance species. Lack of recruitment above upstream reservoirs and low numbers in downstream reaches may indicate escapement and passage difficulties.

Genetics and hybridization

- Species delineation and characterization of diversity are critical. The entire diversity within the genus *Scaphirhynchus* should be examined. How many species exist?
- If voucher *Scaphirhynchus* specimens at museums and university collections exist, morphological and (if possible) genetic studies should be conducted. If suitable habitat conditions no longer exist or can be rehabilitated in the Missouri River to sustain the entire life cycle of pallid sturgeon, difficult decisions to introduce (reintroduce?) pallid sturgeon in other drainages may be required.
- Other possible causes of hybridization among *Scaphirhynchus* in the Missouri River basin could include too much spawning habitat in the Missouri River, uncoupling of temperature and hydrograph that may alter the timing of reproduction and bring the two species closer together in time, and impaired reproductive maturation or function (e.g., contaminant exposure) that may affect sex ratios or disrupt the timing or synchronization of spawning.

Propagation and fish health

- Need to examine internal and external fungi in cultured fish, preventative measures and treatments.
- Need to examine the effects of tagging, especially the large internal sonic or radio tags. Do fish that survived the procedure and were stocked perform naturally in the wild?
- Is fin curling a nutritional pathology or genetic or both? A genetic test using microsatellite markers could facilitate a valuable correlation test between presence/frequency/severity of fin curling and genetic distance (degree of relatedness) of parents contributing to hatchery progeny groups.
- Need to assess the remaining genetic stock in a conservation biology context; i.e. effective population size, population viability analyses, role of fragmentation and connectivity towards restoration of small populations, etc. Do pallid sturgeon comprise a single population or is each management area (or some combination or areas) unique (albeit artificially segregated)?
- Need to describe and study parasites of pallid sturgeon.

- Sturgeon are incredibly hardy under most circumstances but we need to understand what is stressful. The long-term stress associated with the transfer of sturgeon into holding or propagation facilities and stress associated with the spawning of adults requires the most attention.
- Need to determine the most appropriate facility design for sturgeon propagation, especially considering that propagation will likely be needed for a long time.

Lisbon Bottom, Missouri. *Photo courtesy of U.S. Geological Survey.*

Flow manipulations

- Will flow experiments consider whether the draw-down of downstream reservoirs needs to be timed to coincide with upstream dam releases to increase the number of miles of riverine habitat available for sturgeon and other native species?
- There is a pressing need for tools to relate year class strength of sturgeon with environmental flow conditions and flow manipulations. Stable isotope analyses, micro-elemental techniques, and other methods have promise and can also be easily used to distinguish between hatchery-reared and wild fish. This could potentially allow hatcheries to elementally mark fish and release them earlier without having to grow them large enough to tag by other means.
- What about control structures on the Kansas or Platte rivers, or other tributaries? Any manipulation of reservoir flows has difficult consequences. However, tributary dams may be manipulated with less political or economic difficulties, allowing investigators time to formulate alternate hypothesis and develop more supporting evidence for larger or more difficult experiments.
- Need to monitor something other than fish for responses to flow and habitat changes? For example, several mussels use sturgeon as hosts to complete their life cycle.

Habitat manipulations

- Establishment of experimental areas in several inter-reservoir reaches has merit. Stocking of sturgeon can occur within these reaches to serve as genetic reserves and as experimental populations. These reaches may not have many of the constraints as open river reaches (e.g., navigation).
- Need to develop appropriate engineering criteria to recreate habitat complexity and to describe to engineers how it works. Experts should also strive to create biologically-based performance criteria for habitat projects.

- Need to develop complexity criteria on habitat manipulations that may be just as beneficial as "shallow-water." For example, develop methods to increase bluff and bedrock exposure. Create spawning habitat and monitor it in place. Develop engineering solutions to increase channel complexity, to divide flows in and near the main channel to increase areas of flow convergence, and to replace critical winter habitat of large-bodied riverine species (deep, slow habitat) that may have been lost through modification of engineered structures.
- Evaluate constructed habitat and the mainstem portion of the river that it impacts. Adult pallid sturgeon are unlikely to use many of the constructed habitats but they are likely to use adjacent areas where flow convergence occurs as water moves through constructed habitat and returns to the main channel.
- The impact of a structure or habitat element is not always best measured by total acreage. Relatively small elements can provide disproportionately significant benefits over a much wider area, and can benefit many fish.

Other

- Conduct a comparative analysis of extinction and extirpation patterns of *Scaphirhynchus* species throughout their ranges, including the Mississippi, Ohio, Alabama and the Rio Grande Rivers, in relationship to causative factors. What about ecological equivalents, such as the *Pseudoscaphirhynchus* species and the ecosystem that they depend upon (similar in some respects to the Missouri River)?
- Are habitat changes the dominant factor in the apparent decline of pallid sturgeon?
- Need long-term population assessments for pallid sturgeon and the associated fish community. Develop and adopt methods for detecting changes in important population parameters in very rare species. What changes in catch-per-unit-effort can we reliably detect? What is a biologically or statistically significant response?
- Need fundamental research on sensory cell morphology and function, detection limits of sensory organs, morphological adaptations, tolerance limits to temperature and dissolved oxygen, etc.
- Use shovelnose sturgeon commercial harvest to assess population parameters and gear selectivity issues. Monitor commercial fishermen to collect age, growth or tissue samples of the portion of the population that the commercial fishermen are harvesting.
- Need to assess the impact of commercial fishing on sturgeon. Examining the commercial catch will also help to determine if larger, older reproductive adults are being sufficiently sampled.

- Need to develop techniques and gear to collect large, adult pallid sturgeon in large, open rivers. While there is much emphasis on monitoring methods and larval fish collection, there is little mention in the report of the paucity of adults collected in the Lower Missouri or Middle Mississippi Rivers in reproductive condition.
- Adequate spatially explicit population models and Population Viability Analyses (and the subsequent sensitivity analysis of important variables) are needed to guide research and monitoring efforts.
- Determine whether management or hatchery practices for non-native species, or for the enhancement of sport fishes, may conflict with pallid sturgeon recovery through the introduction of competitors, predators, and diseases; through water management practices; or through the continuance of fisheries (recreational and commercial) with a high potential for incidental take of pallid sturgeon.
- What is the impact of dredging and gravel mining operations on pallid sturgeon and native fishes?

Appendix G— Review Comments from the Missouri River Natural Resources Committee

Note: the Missouri River Natural Resources Committee (MRNRC) was represented at the workshop by Gerald Mestl from the Nebraska Game and Parks Commission. The MRNRC reviewed a draft of this report following the workshop and responded in the following letter.

MRNRC

Missouri River Natural Resources Committee
1434 316th Lane, Missouri Valley, Iowa 5I555 712-642-4I2I Fax 7I2-642-2460
October 28, 2004

Ms. Ann Boelter
Research Associate
William D. Ruckelshaus Institute of Environment and Natural Resources
University of Wyoming Dept. 3971
1000 E. University Avenue
Laramie, Wyoming 82071

Dear Ms. Boelter:

As per your request, Missouri River Natural Resources Committee (MRNRC) state agency representatives have reviewed the September 15, 2004 draft *Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River.*

The document is well written and identifies many important research questions that, if answered, should help managers better understand, manage, and hopefully recover pallid sturgeon. However, as noted in our position statement at the May workshop in Bloomington, Minnesota, we believe that adaptive management experiments involving a warm water spring rise out of Fort Peck, reduced summer flows, and a spring rise out of Gavins Point are the best means to answer many of the critical questions. And, based on best available information, these experiments may prove beneficial to pallid stur-

geon. Paralleling these efforts should be a rigorous monitoring and assessment program for the recently constructed habitat projects in the Lower Missouri River.

The MRNRC is currently working with various state, federal, and private partners on a five-year biomonitoring and assessment project in the Middle Missouri River. One component of the project is analyzing the long-term Missouri River Historical Database to identify relationships among fish and invertebrate recruitment and abundance and river flows, temperature, and turbidity. This component promises to provide important information regarding flow experiments based on empirical data and is scheduled to be completed in the summer of 2005. We believe that the highest priority research effort now should be the design, planning, implementation, and evaluation of flow, temperature, and turbidity tests from Fort Peck and Gavins Point Dams.

There is reference throughout the document about the need to reduce uncertainty related to pallid sturgeon recovery efforts. While certainty is better than uncertainty, it needs to be very clear that uncertainty should not preclude attempts to implement recovery actions based on best available information and professional judgment, pending more definitive research results. One obvious obstacle to overcome for most of the life history work is adequate numbers of all life stages of pallid sturgeon in the river environment. We doubt there is sufficient time to overcome this hurdle within the five-year time frame of the intended research let alone conduct the proposed studies. In the near-term, only flow and habitat experiments hold promise to reduce uncertainty.

We caution against any conclusions about preferred habitat use, food preferences or responses to environmental cues in the modified environments of the Lower Missouri River versus less modified habitats upstream in the basin. Measurements of these and other parameters reflect the pallid sturgeon's ability to adapt to or tolerate current conditions and do not necessarily represent the species' preferences. Pallid sturgeon populations in the Missouri River and the habitats they occupy are not a single, homogenous, contiguous entity. Fish in the upper basin are larger, have little to no incidence of apparent hybridization, and occur in more natural, unchannelized habitat. Indeed, to-date findings from the "Population Structure and Habitat Use of Benthic Fishes Along the Missouri and Lower Yellowstone Rivers" denote the inherent complexity in this system among river reaches in habitat characteristics and growth, recruitment, and abundance of native fishes. Pallid sturgeon in the channelized river may use wing dike scour holes and other unique structure simply because there is no other habitat available in the relatively homogenous main channel. This does not mean this habitat is preferred; it means that is all there is.

Therefore, for many of the recommendations in the document, the results from one area may not be applicable to the other area due to these differences. Where applicable, we recommend that the research recommendation be specific to the portion of the basin where the results are intended to be applied. Caution must be used in applying site-specific (and lab) results on a range-wide basis.

For example, there are recommendations to use the Fort Randall reach and the pallid sturgeon therein as a demonstration area because temperatures and flows can be manipulated. This sounds ideal, but please keep in mind that this is a very short reach (45 miles), and the pallid sturgeon within this reach are behaving differently than in other areas. Recent diet studies of Ft. Randall fish indicate they are eating primarily invertebrates, whereas the same aged pallid sturgeon in the river above Ft. Peck Reservoir are almost exclusively piscivorus. Native cyprinids such as flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow that are normally associated with pallid sturgeon in reaches where they occur are absent from this (the Fort Randall) reach. Although it is possible to manipulate flows in this reach and perhaps temperature, there are no significant sources of sediment and nutrients in the reach until the confluence of the Niobrara River where the Missouri River transitions into a lake environment. The delta formed by the Niobrara River is rapidly converting river habitat into a lentic environment in the transition area and the reach has significantly different water temperatures and turbidity levels compared to other semi-natural reaches inhabited by wild or hatchery-produced pallid sturgeon.

Alternatives to using the Fort Randall reach should be explored including installation of a selective withdrawal device on Fort Peck Dam and a flow test below Gavins Point Dam. The former would allow experimentation with temperature modifications and possibly spawning flows at reduced levels until storage is adequate for a full test. Experimentation in the Fort Peck reach is desirable given that significant numbers of adult pallid sturgeon are already tagged, telemetry and sonic receiving stations are in place, monitoring teams are already established and working, and baseline data regarding the movement of pallid sturgeon and other native species is available.

Prioritization of research recommendations is strongly supported by the MRNRO and should be the next step in the process. Some recommendations are obviously more important than others. For example, if larval drift into reservoirs is the reason there is no recruitment (in the Upper Basin), then it is more important to address that issue before spending a lot of time and money on enhancing spawning habitat where pallid sturgeon currently spawn, or determining the survival of larval fish that will ultimately end up in Lake Sakakawea. Other examples are the fish health and propagation related recommendations which are not necessary if propagation protocols are followed. We already have a pretty good idea of what triggers iridovirus outbreaks (high densities and stress), and can reduce the priority for studying impacts of iridovirus if we take all available precautions to prevent the outbreak of it in the first place.

Many of the research issues are already being addressed in some fashion in some parts of the range of pallid sturgeon. For example, in the Upper basin, there is a tremendous amount of radio-telemetry monitoring of fish occurring in anticipation of a spring rise out of Ft. Peck, with hopes of measuring a response of big river fish to the increased flows of warmer water. Larval drift tests have occurred. Hatchery reared pallid sturgeon are being radio-tracked to determine movement and behavior after stocking. Food

habits and habitat use are being investigated in Recovery Priority Management Area (RPMA) 1. Standardized monitoring is being implemented by the Corps of Engineers, Fish and Wildlife Service, and various state agencies in all of the other RPMA'S.

Finally, it should be made clear in the discussion concerning monitoring and evaluation of "created" shallow-water habitat, that habitat function for pallid sturgeon or lack thereof is related to site-specific flow levels. If created habitat is designed only to function at certain target flows it may not be directly applicable to other habitat creation projects or flow management elsewhere in the system.

As you can see, most of the infrastructure and data necessary to conduct flow tests and monitor habitat projects in the lower river are already in place or soon will be. That being the case, the first priority for research funds should be the design, planning, implementation, and evaluation of adaptive management flow experiments utilizing the expertise of the United States Geological Survey, the Corps of Engineers, the U.S. Fish and Wildlife Service, the states, stakeholders, and independent science advisors. Thank you for the opportunity to review the draft proposal. Please feel free to contact me at 573-522-4115 Extension 3371 if you have any questions, or if I can be of any further assistance. The MRNRC stands ready to assist this effort.

Sincerely,

BRIAN D. CANADAY
MRNRC CHAIR
MISSOURI DEPARTMENT OF CONSERVATION

cc: MRNRC Delegates

MRNRC State Agency Membership: Montana Department of Fish, Wildlife, and Parks - North Dakota Game and Fish Department - South Dakota Department of Game, Fish, and Parks - Nebraska Game and Parks Commission - Iowa Department of Natural Resources - Kansas Department of Wildlife and Parks - Missouri Department of Conservation