Sustainable Ecosystems Institute

Independent Science Review of the Pallid Sturgeon Assessment Program: Final Report

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Independent Science Review of the Pallid Sturgeon Assessment Program: Final Report

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Independent Science Review of the Pallid Sturgeon Assessment Program: Final Report

EXECUTIVE SUMMARY

This document is the final report of an Independent Science Review of the monitoring and assessment program for the endangered Pallid Sturgeon. At the request of the Pallid Sturgeon Monitoring and Assessment Team, the Sustainable Ecosystems Institute (SEI) convened an independent science panel who reviewed materials, and met with the assessment team, researchers and managers to evaluate the program. The team comprised five experts in fish ecology, monitoring, river systems, sturgeon biology, population modeling, statistical and experimental design, and science-policy. The panel was supported by an ecological statistician who carried out a separate power analysis. This analysis was also used by the panel in their evaluation.

The report comprises three stand-alone sections: a synthesis of the monitoring program and review process; key findings; and recommendations and suggestions for future monitoring and assessment. The power analysis is appended.

The Pallid Sturgeon Monitoring and Assessment Program has multiple components, reflecting the information requirements set out in an earlier Biological Opinion. These information needs included: the survival, movement, distribution, habitat use and physical characteristics of habitat used by wild and hatchery reared and stocked juvenile Pallid Sturgeon, as well as information related to a series of native Missouri River species. To date, the Pallid Sturgeon monitoring and assessment program has been implemented in five of fourteen segments with one to two years of data available. The Pallid Sturgeon Assessment Team expects full implementation in 2005.

The review focused on four issues:

- The current design of the monitoring and analytical program
- The technical approaches in use
- The implications of statistical analysis for monitoring design
- Suggestions for adaptive monitoring to maintain the program as a living program, including institution steps that the team can take to improve the effectiveness and utility of the program.

KEY FINDINGS

The panel concluded that the Pallid Sturgeon monitoring and assessment program, as designed and executed through two initial years, is well-conceived, follows standard practices and constitutes a credible start on a long-term monitoring program. Progress to date is at least comparable to that of other large American ecosystem restoration initiatives at this stage in their development. The approaches in use more that meet the process and analytical standards of mainstream science. Although the program has areas that warrant improvement or re-thinking, the reviewed documents reflect the first steps of a solid, state-of-the-art ecosystem assessment.

Element-by-element, the components of the monitoring program are sound and represent standard scientific practices. However, they could be better integrated and better tied to the articulated information needs of managers and policymakers.

Power analysis identifies some investments and trade-offs that must be considered in the final design of a comprehensive monitoring program.

The panel was generally impressed with the level of cooperation and coordination among the people and programs that met with them. Technical and statistical integration are more challenging, in part simply because of the complexity of both the river system and the many somewhat-related facets of the monitoring programs. The most important need is to develop more expertise, possibly either in the form of a standing external technical advisory body or as new staff (or both) in statistical design and trend/power analysis, and to perform regular reviews of whether the design and monitoring data are yielding the information needed to inform policy.

RECOMMENDATIONS

Big Picture Recommendations

- Conceptual Models: The panel recommends that the Team and associated program institute a formal conceptual modeling process analogous to that of other large ecosystem restoration initiatives.
- Designate core monitoring activities: Separating core activities from other activities may help focus resources on the most important applications and assessment
- Develop and utilize technical expertise. Because of the complexity of the program and strong technical challenges, the team would benefit from a technical working group.
- Use adaptive monitoring

- Regularly review the program both internally and externally. This includes independent external review and power analyses.
- Develop mechanisms to feed results into management and monitoring.

Statistical Recommendations

- Form a statistical advisory "group" that comprises expertise on statistical design, trend analysis, power analysis, and remote sensing and telemetry data. Consider a statistician on staff or "retainer".
- Regularly reevaluate and adapt in light of new information.

Technical Recommendations

- Clarify geographical and management units.
- Separate habitat and population monitoring.
- Utilize two sampling seasons with separate key objectives.
- Create a formal mechanism for dealing with exploring great types, efforts so that they enhance information without interfering with statistical and analytical power.
- Evaluate trend analysis to assess the degree to which achievable statistical certainty meets management needs and expectations.
- Evaluate different life-history stages.
- Use appropriate caution in interpreting results from surrogate species including Shovelnose Sturgeon.
- Consider event-based triggering of more intensive sampling.
- Evaluate the use of demographic models including individual based models.

Recommendations on Genetic Information Needs

- Evaluate whether new methods can and should be deployed now to address characterization boundaries, movement, hybridization and identification of individuals.

Research Recommendations

- The panel supports ongoing investment in research identified by the Pallid Sturgeon Monitoring and Assessment Team, including research on telemetry, hybrid viability, spawning and early life stages of the Pallid Sturgeon.

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PROJECT OVERVIEW AND REPORT STRUCTURE

The Pallid Sturgeon Assessment Team, convened by the US Army Corps of Engineers (USACE) requested that Sustainable Ecosystems Institute (SEI) conduct an independent scientific review of the monitoring and assessment program for the endangered Pallid Sturgeon. The team specifically requested that the panel evaluate the monitoring program's design and ability to address particular aspects of the Biological Opinion, provide recommendations on adaptive monitoring for the program, and carry out a power analysis to evaluate the ability of the program to detect population trends in the Pallid Sturgeon. The Independent Science Review panel met formally with the assessment team, the researchers, and other participants in a facilitated forum in October 2004 in Sioux Falls, S.D. to discuss and review the program (Sioux Falls Workshop 2004 CD). Shortly afterwards the Review Panel met in Portland Oregon to finalize their review. This document is the final report of the Independent Science Review panel. Results of the power analysis are available in a separate report (Peery, 2004) but specific results are discussed here where relevant to individual topics.

REPORT STRUCTURE

This report is divided into three main sections. 1. Review goals and activities, 2. key findings 3. Detailed discussion, suggestions and recommendations. This chapter describes the objectives and process of the independent science review, as well as the main features of the Pallid Sturgeon monitoring and assessment program which was reviewed by the panel. The next chapter gives the main findings of the independent review panel. The subsequent chapters are a detailed discussion of the panel's recommendations and suggestions which are intended to provide assistance to the Population Assessment Team as they move forward. These sections are organized by theme. Thus the section on population processes provides interpretation on the power analysis and how the team might use the information. The section on survey design discusses opportunities for increasing power and detection levels. Each of these sections concludes with a list of specific recommendations for the program. The last chapter contains a summary of the main recommendations.

The sections of this report are designed to stand alone, and had differing primary authors, although every panel member has extensively reviewed and supports the overall assessments. There is therefore occasional repetition of information where knowledge of some particular aspect of the program is needed in order to set the context for a specific comment or recommendation.

BACKGROUND

In 1990, in response to the low numbers and a declining trend in Pallid Sturgeon *Scaphirhynchus albus* populations the US Fish and Wildlife Service (USFWS) listed the species as endangered under the Endangered Species Act (ESA). Since then Missouri River Pallid Sturgeon abundance has remained low and populations have not shown signs of recovery.

In its role as the water management agency responsible for the Missouri River Basin, the USACE consulted (under Section 7 of the ESA) with the USFWS regarding conservation of the Pallid Sturgeon and other listed species in relation to its river management plans and activities. Over a ten year period the USACE and USFWS conducted formal and informal section 7 consultations. Then, in 2000 the USFWS issued a Biological Opinion (BiOp 2000) on the operations of the Missouri River Mainstem Reservoir System, the Missouri River Bank Stabilization and Navigation Project, and the Operation of the Kansas River Reservoir System. The Biological Opinion addressed the Pallid Sturgeon as well as three additional species listed under the ESA. The USACE reinitiated consultation in July 2003 to address some of the Reasonable and Prudent Alternative (RPA) elements of the Biological Opinion and in November 2003 the USFWS issued an Amendment to the 2000 Opinion (BiOp Amendment 2003).

The overall goal of the Biological Opinion is the restoration of the form and function of the Missouri River, including physical and hydrological restoration; habitat and river process restoration; fledge ratios, spawning cues, reproduction, recruitment, and connectivity (M. Olson USFWS 2004). Within the Biological Opinion, elements of the entire Pallid Sturgeon RPA include adaptive management, Fort Peck flow changes and temperature control device, unbalanced intrasystem regulation, population assessment (the focus of this Independent Science Review), Gavin's Point flow changes, population augmentation, and habitat restoration/creation and acquisition.

The Biological Opinion 2000 and Amendment 2003 addressed the sturgeon's inability to naturally reproduce and the need to be able to detect any change in the population and ecosystems trends. Because the numbers of Pallid Sturgeon are so low, the Biological Opinion called for a long term population assessment approach that included other native Missouri River species in addition to the Pallid Sturgeon. The Biological Opinion included specific information to be included in the population assessment for the Pallid Sturgeon: 1. total number of fish captured and tag number; 2. GPS coordinates of capture sites, distribution, recapture incidence and numbers; 3. channel and substrate mapping of the habitats used by the fish; 4. tributary use and concentrations by Pallid Sturgeon; 5. temperature, surface and bottom velocity, turbidity, and depth at capture locations; 6. size (length of fish) frequency; 7. morphological measurements and meristic counts; 8.

species characterization utilizing morphological measurements; 9. genetic analysis of fish; and 10. productivity and recruitment.

THE PALLID STURGEON MONITORING AND ASSESSMENT PROGRAM

To address elements of the Biological Opinion, the USACE assembled a Population Assessment Team composed of representatives of state and federal agencies and universities affiliated with Missouri River fisheries projects and/or Pallid Sturgeon projects, who collectively represent Pallid Sturgeon expertise in the geographic region of the project. The team was convened to develop and oversee the monitoring scheme and protocols that make up the assessment program. The Pallid Sturgeon population assessment program is guided by the Biological Opinion and proposes to accomplish the RPA goals in part through a comprehensive monitoring plan designed to assess the survival, movement, distribution, habitat use and physical characteristics of habitat used by wild and hatchery reared and stocked juvenile Pallid Sturgeon, as well as to track trend information related to a series of native Missouri River species (Population Assessment Team, Draft July 2004).

The key objectives of the program are to:

Document current and long-term trends in Pallid Sturgeon population abundance, distribution and habitat use throughout the Missouri River system

Document survival, growth and habitat use of stocked Pallid Sturgeon in the Missouri River system

Document Pallid Sturgeon reproduction and recruitment in the Missouri River system

Document current and long-term trends in native Missouri River fish species abundance, distribution and habitat usage, with emphasis on warm water benthic fish community

In designing the program, the team took advantage of the existing benthic fish assessment program and used it as the framework for the Pallid Sturgeon program (Pallid Sturgeon Assessment Team, Draft July 2004; Wildhaber, 2004). The basic design of the program is a stratified random sampling design. The sample unit is the river bend, stratified by river segment. There are 14 segments (see Figure 1). Within the bend a variety of different habitats are sampled using a range of gear types (see below).

Figure 1. Pallid Sturgeon monitoring and assessment program segment map.

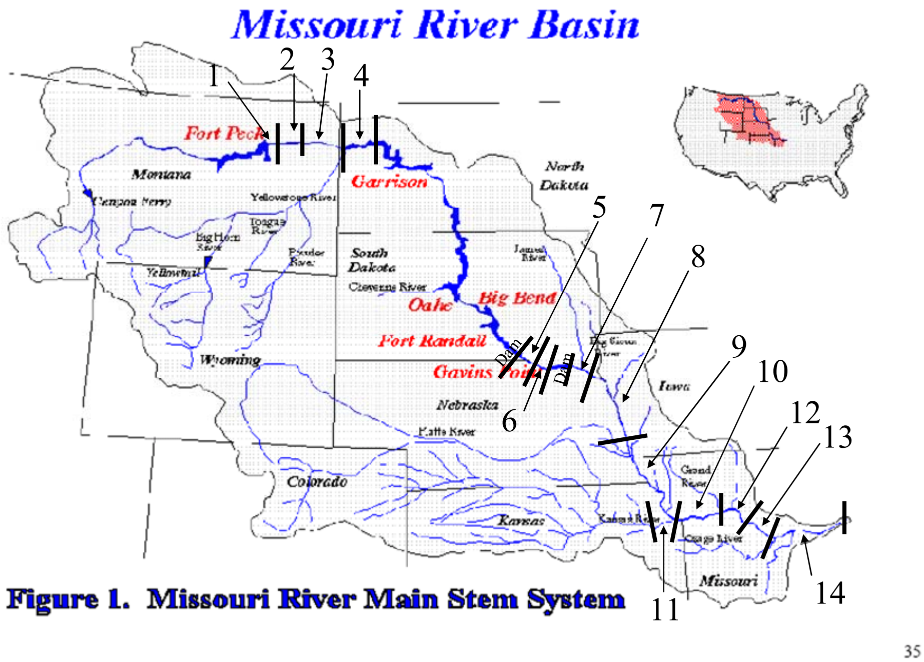


Figure 1. Missouri River Main Stem System

CURRENT STATUS

To date, the Pallid Sturgeon monitoring and assessment program has been implemented in five of fourteen segments (Segments 5, 6, 9, 13 and 14) with one to two years of data available. While the assessment survey and sampling protocols have been followed in each of these segments, the researchers have also investigated the use of other gear types e.g. set lines, and carried out extra effort beyond that required by the protocol (e.g. Pallid Sturgeon Independent Science Forum, see e.g., Stancill, et al. 2004). The Pallid Sturgeon Assessment Team expects full implementation (i.e. sampling all 14 segments of river) in 2005. Among the next steps that the team hopes to address are to contract for the data entry and storage of the monitoring program, and standardizing of reporting methods and formats.

INDEPENDENT SCIENCE REVIEW: GOALS AND ACTIVITIES

The Pallid Sturgeon Assessment Team requested an Independent Scientific Review (ISR) of the Pallid Sturgeon monitoring and assessment protocol to assist them in their efforts to maintain and manage the Pallid Sturgeon population. Sustainable Ecosystems Institute was asked to carry out this review.

The objectives of the Pallid Sturgeon monitoring and assessment program are driven by the Biological Opinion. Consequently the assessment methods are designed to meet specific requirements of the RPA of the Biological Opinion, specifically those related to detecting trends in population abundance, habitat use, reproduction and recruitment of wild and stocked Pallid Sturgeon. An additional requirement of the Biological Opinion is to monitor native fish as indicators of Pallid Sturgeon and ecosystem condition. The charge to the science panel was to conduct an independent scientific review and address whether the design, methodology, and analysis sufficient to document:

- current and long term trends in Pallid Sturgeon population abundance, distribution and habitat use
- survival, growth and habitat use of stocked Pallid Sturgeon
- Pallid Sturgeon reproduction and recruitment in the Missouri River
- current and long-term trends in native Missouri River fish species

A second important component is to provide recommendations regarding an "Adaptive Monitoring Process" for maintaining this assessment program as a living program. An additional charge for SEI was to conduct a power analysis to help assess the ability of the program to detect statistically meaningful changes in abundance of Pallid Sturgeon, with input and oversight from the review panel. The guiding document for the review is the *Long-term Pallid Sturgeon and Associated Fish Community Assessment for the Missouri River and Standardized Guidelines for Sampling and Data Collection* (hereafter "protocol"; Pallid Sturgeon Assessment Team, Draft July 2004). The ISR panel was not asked to consider other elements of the Biological Opinion such as hatchery programs or adaptive management.

Sustainable Ecosystems Institute convened a panel of scientists to provide an independent review of the assessment program including overseeing a power analysis. The panel consisted of Dr. James Quinn (Chair); Dr. Michael Bozek; Dr. Deborah Brosnan; Dr. Henrietta Jaeger; and Dr. David Secor. The review panel, Population Assessment Team, researchers and other participants met formally at the Independent Science Review forum held in Sioux Falls South Dakota on October 27-28, 2004. The meeting was a facilitated forum using the SEI process to foster an open, transparent articulation and debate of the science. Dr. Steven Courtney (SEI) was the science-facilitator for the forum, and Lisa Sztukowski (SEI) acted as project lead. Details of this process and of the forum itself are provided in a separate report, Independent Science review of the Pallid Sturgeon Assessment Program: Science Review Forum (SEI, 2004). The panel met again in November 2004 to discuss and write up their findings. This document is the final report of the findings and recommendations of the Independent Review Panel.

The power analysis was carried out by Dr. M. Zachariah Peery (SEI, UC Berkeley) with oversight by the review panel. Results of the power analysis are available in a separate report (Peery, 2004) but specific results are discussed here where relevant to individual topics. (See for example, the Population Processes: Trend Analysis chapter in this report.)

The Pallid Sturgeon Assessment Program: Overview and Key Features

The project area for the Pallid Sturgeon Assessment encompasses the Missouri River from Fort Peck Dam, Montana at Rivermile 1771.5 downstream to the confluence of the Missouri and Mississippi Rivers near St Louis Missouri at Rivermile 0 (see Figure 1 above). The Pallid Sturgeon Assessment design is based on that of the Benthic Fishes Survey (Galat, et al. 2002, Wildhaber, 2004). It is a modified stratified random sampling design where the bend is the fundamental sample unit, stratified by river segment (Table 1). The river has been divided in fourteen segments (Table 2). Within each segment either 8 random and 2 non-random (fixed locations of particular interest) bends, or 4 random and 1 non-random bends (or some similar combination depending on the size of the segment) are sampled (see Table 2). The random bends are re-selected on each sampling round. Sampling targets twelve macrohabitats within each bend (replicate sampling unit) - See Figure 2. Areas within each macrohabitat have been divided into mesohabitats, which include pools, bars, channel borders, and thalwegs. Mesohabitats occur in a variety of macrohabitats so that, for instance, pools (mesohabitats) occur in outside bends and in crossovers (Figure 3).

Table 1. Overview of the stratified sampling design used in the population monitoring and assessment program

	Protocol/Operating procedure
Missouri River	
Segment	14
Bend	3-10 bends/segment
Macrohabitat	Variable, all available
Mesohabitat	Variable, all available
Gear	2-3
Subsample	≥ 2

Table 2: Pallid Sturgeon river segments. Image c*ourtesy of Wilbhaber 2004*

Pallid Assessment Segments

Segment Number	Total River Bends	Randomly Selected River Bends	Chosen River Bends
Segment 1 Fort Peck Dam to Milk River	1	0	1
Segment 2 Milk River to Wolf Point (Hwy 13 bridge)	10	8	2
Segment 3 Wolf Point to Yellowstone (Confluence)	10	8	2
Segment 4 Confluence to Headwaters (Sakakawea)	10	8	2
Segment 5 Fort Randall Dam to Niobrara (Confluence)	5	4	1
Segment 6 Confluence to Headwaters (Lewis & Clark)	5	4	1
Segment 7 Gavins Point Dam to L. Ponca Bend	10	8	2
Segment 8 L. Ponca Bend to Platte River (Confluence)	10	8	2
Segment 9 Platte R. to the Kansas River (Confluence)	10	8	2
Segment 10 Kansas R. to the Grand River (Confluence)	10	8	2
Segment 11 Kansas River from the Johnson County Weir to the Confluence with the Missouri River	3	3	0
Segment 12 Grand R. to Glascow, MO.	4	3	1
Segment 13 Glascow to Osage River (Confluence)	10	8	2
Segment 14 Osage R. to the mouth	10	8	2

Figure 2: Macrohabitats. Image courtesy of Stancill et al. 2004

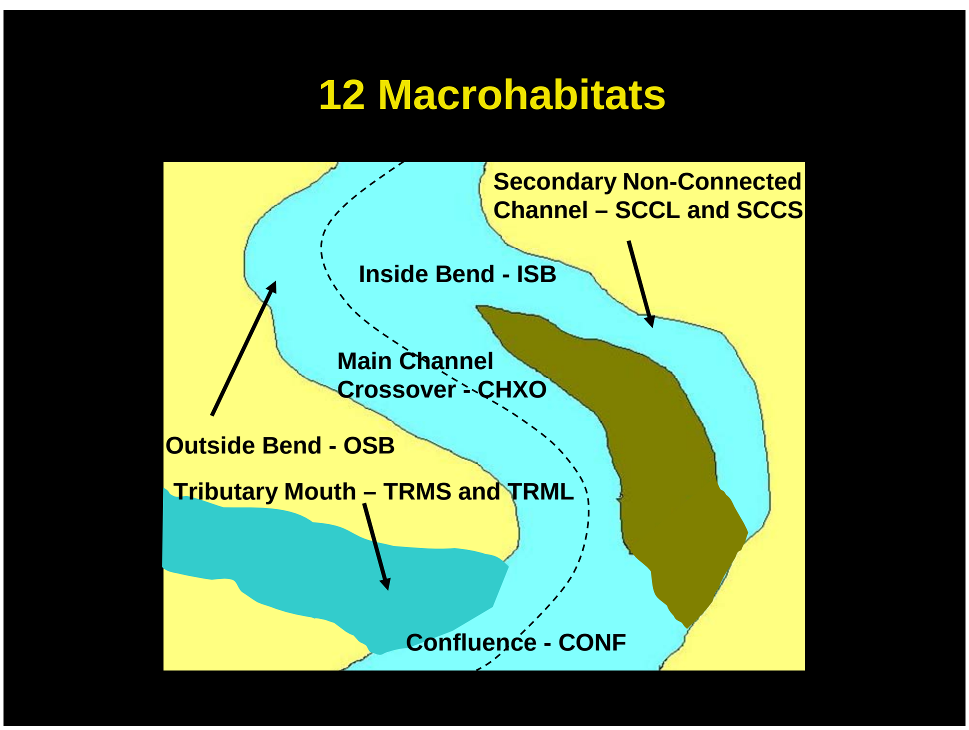
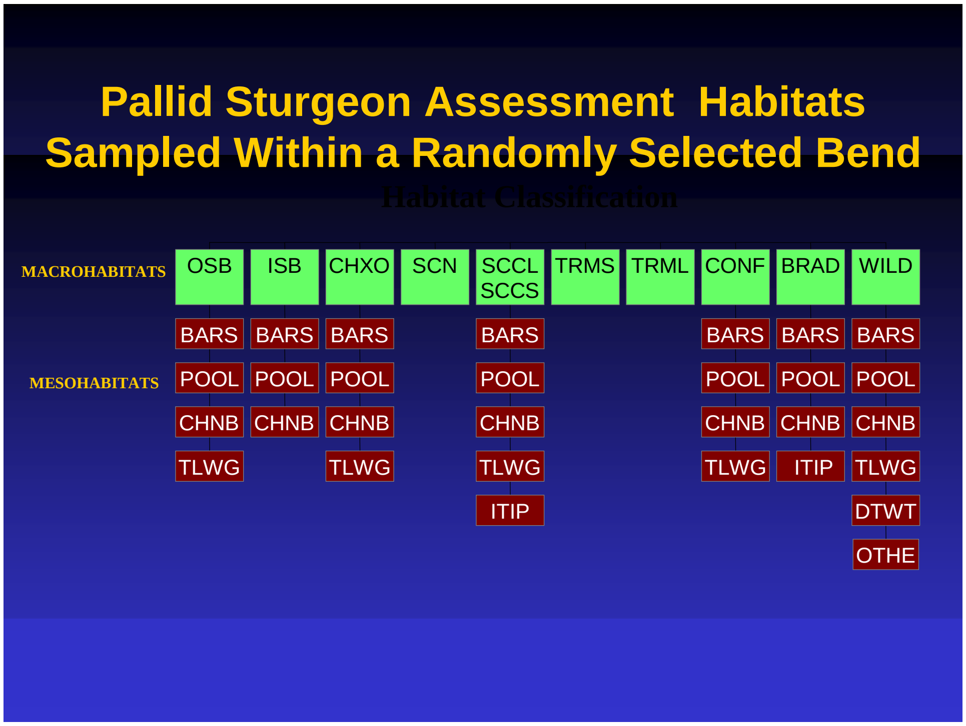


Figure 3: Pallid Sturgeon assessment habitats sampled within a randomly selected bend
Image courtesy of Wildhaber 2004



The actual number of bends varies among segments, and because of the dynamic nature of the river the number of bends can vary among years. Consequently the proportion of bends per segment is not equally sampled across all segments. For instance, in 2003 the number of bends per segment ranged from 3 to 81 bends per segment (in segments 1-14).

Two sampling seasons have been established to target the four objectives of the program. These seasons are determined by dates and water temperatures in order to provide flexibility in sampling across the geographic range of the Missouri River Basis (Pallid Sturgeon Assessment Team, Draft July 2004). See Table 3.

Table 3 Sampling seasons

Sampling Season	Duration	Comments
Sturgeon Season	Begins when water temperatures $\leq$ 12.8 ^{o} C. and extends to June 30th	
Community Fish Season	July 1-October 31	No gill net sampling allowed unless water temperatures drop below 12.8 ^{o} C

The Sturgeon Season begins in the fall when the water temperature is ≤ 12.8 ^{o} C. and continues through June 30th. The season start date is temperature dependent in order to reduce the potential for take (under ESA) during sampling activities (USFWS 2002). (To avoid unnecessary take, gill nets must not be set when the water temperatures exceed 12.8^{o}C.) Because of this the timeframe for the sampling, gill net sampling effort may vary significantly throughout the Missouri River basin. In parts of the river, e.g. the upper river, the amount of time in the field season to accomplish sampling (e.g., gill netting) prior to ice up of the river may be restricted. Other than for gill netting, summer sampling efforts remain the same but with an additional emphasis on the associated fish community. The Fish Community Season runs from July 1 through October 31. These two seasons may overlap in portions of the river when water temperatures fall below 12.8^{o} C prior to the conclusion of the Fish Community Season.

Part of the Sturgeon Season (i.e. when water temperature ≤12.8 ^{o} C) enables crews to deploy standardized experimental mesh gill nets. Gill netting during the Sturgeon Sampling Season may not be feasible in all segments due to environmental factors which vary from year to year. A variety of complimentary gears are deployed throughout the habitats primarily from March through June. The program is designed with a required sampling effort and with flexibility to allow for additional sampling and investigations by the field crews (see e.g. Stancill et al 2004, Independent Science Review Forum 2004).

The Sturgeon Sampling Season is designed to provide trend information regarding Pallid Sturgeon abundance and distribution, evaluate the success of the ongoing population augmentation program, and provide information related to dispersal, staging and spawning areas of Pallid Sturgeon.

The Fish Community Season has an equivalent level of sampling, excluding gill netting, during late summer and fall, but places an additional emphasis on the fish community. Additional sampling using passive (e.g., mini-fyke nets) and active (e.g., seine) gears are used to provide information related to species composition of fish using shallow water habitats (<1.2m). Sampling is also designed to provide an assessment of young-of-the-year fish production. In addition, sampling at this time of year provides the greatest opportunity to document natural reproduction via sampling young-of-the-year Pallid Sturgeon (Pallid Sturgeon Assessment Team, Draft July 2004).

In addition to the Pallid Sturgeon, ten native species are targeted during the Fish Community Season. These are: Shovelnose Sturgeon *Scaphirynchus platorynchus*; Sand Shiner *Notropis stramineus*; Sicklefin Chub *Macrhybopsis meeki*; Sauger *Stizostedion canadense*; Plains Minnow *Hybognathus placitus*; Western Silvery Minnow *Hybognathus argyritis*, Speckled Chub *Macrhybopsis aestivalis*; Sturgeon Chub *macrhybopsis gelid*; Blue Sucker *Cycleptus elongates* and Bigmouth Buffalo *Ictiobus cyprinellus*. These native species were chosen for a variety of reasons. Some appear to co-occur with the Pallid Sturgeon e.g. Shovelnose Sturgeon, and Blue Suckers. Others are indicators of particular riverine conditions e.g., Sauger are associated with high turbidity, Bigmouth Buffalo are associated with floodplains, and Sand Shiner and Plains Minnow are indicators of natural flow conditions. Sicklefin Chub were candidates for listing under ESA. Apart from the Shovelnose Sturgeon, all these species have shorter lifespans than the Pallid Sturgeon and thus population response times may be faster. Hence these species may provide information valuable to managers well before direct evidence on population responses of Pallid Sturgeon become available.

GEAR TYPES

Standardized gears have been selected for targeting specific habitat types for the Sturgeon and Fish Community Sampling Seasons (see Table 4). A minimum number of gear deployments for each standard gear has been established per bend to ensure adequate representation for comparisons between segments (see protocol below). These gear types have been selected for a variety of reasons. Some are designed specifically to capture Pallid Sturgeon while others focus more on the fish community. However, the gears are not species-specific and will sample a range of fish species. The deployment of wild "W" gear (e.g. set lines) is optional and may be used in addition to the standard gear/habitat combinations. This allows crews to experiment with a variety of capture techniques.

Table 4: Pallid assessment gear application. *Image courtesy of Wildhaber 2004*

Pallid Assessment Gear Application

Macrohabitats	OSB, ISB, CHXO, SCCL, SCCS, CONF					SCN	TRMS	TRML
Mesohabitats	BARS	POOL	CHNB	TLWG	ITIP*			
Gears								
Bag Seine	S (S)					S (S)	S	S
Minifyke Net	S					S	S	S
Trammel Net		W	S (S)	W	S		W	W (S)
Otter Trawl		W	S	W	S	W	W	S
Hoop Net		W	S**		W	W	W	S**
Beam Trawl		S	W (S)	W	W	W	W	W (S)
Set Line	W	W	W		W		W	W
Electrofishing			S			S	S	S
Stationary Gill Net		S				S	S	

Protocol for Sturgeon and Fish Community Sampling

Once a river bend is selected, all macro and mesohabitats should be identified
1) Each mesohabitat within a macrohabitat should be sampled using the standard gears (usually 2 or 3 gears/mesohabitat). Note that standard gears differ between sturgeon versus fish community sampling protocols and seasons
2) Two sub-samples are required for each standard gear for the habitats identified within a bend
3) Additional sampling (optional) may be conducted and identified as "Wild" on the datasheet
4) Habitat characteristic data collection (velocity, substrate, turbidity) is required in conjunction with 1 sub-sample per mesohabitat (within a macrohabitat) for each gear type, habitat characteristic data will be collected at a minimum of 25% of all subsamples collected within a mesohabitat for each gear type
5) Depth and temperature will be collected at all sampling locations.

SAMPLING RESULTS AVAILABLE TO THE PANEL FOR REVIEW AND FOR POWER ANALYSIS.

By the time of this review in October 2004, five segments had been sampled according to the protocol and one year of data were available for review and power analysis.
Segments sampled were:
Segments 5 and 6: US Fish and Wildlife Service, Great Plains Fish and Wildlife Management Assistance Office Pierre, South Dakota, Stancill, et al., Independent Science Review Forum 2004.
Segment 9: Nebraska Game and Parks Commission. Mestl, et al., Independent Science Review Forum 2004.
Segments 13 and 14: USFWS Columbia River Resources Office. Doyle and Starostka, Independent Science Review Forum 2004.

Results from the 5 sampled segments were used for the power analysis which was conducted as part of this review (See Peery 2004 and this report). Because the number of bends per segment varies among segments, the average number of bends sampled per segment was used in carrying out the analysis. Additional analysis of up to 24 bends per segment were included to investigate detection power (Table 5).

Table 5. Overview of stratified sampling hierarchy used in the monitoring and assessment program and in the power analysis.

	Protocol/Operating procedure	Power Analysis
Missouri River		
Segment	14 Segments 1-4 and 5-14 represent two isolated populations	Power analysis model based on 10 segments. Data for power analysis taken from the 5 available from 5 segments
Bend	3-10 bends/segment (average 6 bends per segment)	6-24 per segment
Macrohabitat	Variable, all available	N/A
Mesohabitat	Variable, all available	N/A
Gear	2-3	
Subsample	≥ 2	12-36

As noted above, the variation in the number of bends per segment results in differences among the proportion of bends sampled in each segment. Depending on the approach to sampling, either some fixed number or fixed proportion of bends could be used to set sampling regimes that provide the desired level of detection. For instance the total number of bends in segments 5, 6, 9, 13, and 14 combined was 202 bends (Table 6). The actual number of bends sampled varied from 3-10 bends per segment or an average of 6 bends per segment. As the numbers of bends sampled increases, so does the proportion of bends sampled, which in turn impacts power (Table 7). See the sections on Survey Design and Population Processes in this report for an in-depth discussion of the implications of this and its relationship to survey design and detecting changes in population trends.

Table 6. Total number of bends per segment, and number and proportion of random bends per segment sampled according to current sampling protocol.

Segments currently sampled	Total # bends per segment	# random bends sampled per segment (based on protocol)	Proportion of randomly selected bends sampled per segment (based on bends protocol)
5	17	4	0.235
6	9	4	0.444
9	81	8	0.099
13	39	8	0.205
14	56	8	0.143
TOTAL (all 5 segments)	202	32	0.158

Table 7. Proportion of total bends sampled in active segments, under different sampling scenarios. Scenarios are based on the power analysis See Peery 2004 and this report.

6 Bends	12 Bends	18 Bends	24 Bends
0.124	0.30	0.45	0.594

CHAPTER 2: SUMMARY OF FINDINGS

The panel was asked to report on four major classes of issues:

Does the current design of the monitoring program and analytical framework meet the standards established by comparable large ecosystem restoration initiatives and the accepted professional practices of the ecosystem restoration and fisheries management communities?

Are the technical approaches sound? Could they be made more effective while providing continuity with past efforts?

What can be learned from formal statistical trend and power analysis, and what are the implications for monitoring design and interpretation of monitoring data?

Are there institutional steps that the Missouri River agencies can take to improve coordination and the effectiveness of the monitoring program?

In general, the panel believes that the design of the monitoring programs addressing Pallid Sturgeon in the Missouri River system are soundly conceived, and that progress to date is at least comparable to that of other large American ecosystem restoration initiatives at this stage in their development. As with any landscape-scale multi-institutional effort, there is no single correct approach, and any program is sure to have inconsistencies, gaps in information, and somewhat conflicting goals and mandates among the participants. Most of this document is dedicated to suggestions that might help adjust strategies and protocols to make the scientific information for setting Pallid Sturgeon policy more robust, but we believe that progress to date has been impressive.

Does the current design of the monitoring program and analytical framework meet the standards established by comparable large ecosystem restoration initiatives and the accepted professional practices of the ecosystem restoration and fisheries management communities?

An inevitable question in any high-stakes public policy debate is whether the underlying scientific analysis is independent and should be accepted as valid by the technical community and the public. Public confidence is undermined if it is thought that the process cherry-picked databases, trotted out discredited theories, paid attention only to information policymakers want to hear, performed analyses guaranteed to produce the desired results, or otherwise cooked the data to validate preferred policies. The panel found no suggestion of these kinds of improprieties. Instead, we have an approach that more than meets the process and analytical standards of mainstream science, and stands ready to be debated, refined, and tested by the always-skeptical norms of the scientific community.

The documents reviewed by the panel are not without their flaws. They were assembled by small teams charged with synthesizing a huge volume of data, literature, maps and surveys, and reflect a long history of public and private activities on a large and heterogeneous river system. As the discussion below indicates, they were not completely successful. The writing of some sections is incomplete and conceptual frameworks, cross-referencing and integration all could have been improved. Although the incompleteness, inaccuracies, and uncertainties inherent in all ecosystem-scale datasets and models are readily acknowledged, they are mostly un-quantified. Some of the proposed recovery efforts and research and monitoring plans are probably too ambitious, given the personnel, facilities, and budgets available, and many of the most difficult analyses and decisions have (mostly rightly) been deferred to a later time.

The panel's constructive critiques should not mask the underlying reality. The documents including the monitoring plan documents represent first steps of a solid, credible, state-of-the-art ecosystem assessment. They could have been improved in a number of ways, as can any documents so large and complex. However, they should stand up well to public and professional scrutiny.

Are the technical approaches sound? Could they be made more effective while providing continuity with past efforts?

Element-by-element, the components of the monitoring program are sound and represent standard practices of the community. The panel does not feel that they are as well integrated as they could be, nor specifically enough tied to the articulated information needs of managers and policymakers. At about this stage of development, other large landscape restoration programs, such as the Northwest Forest Plan, Everglades, Columbia River, San Francisco Bay-Delta (CALFED) initiatives, have discovered that developing explicit conceptual models for environmental processes and management decision trees helps focus efforts on critical problems and make assessments more powerful and informative. The next section of this report reviews conceptual modeling approaches. The following sections discuss applications to monitoring design, population processes, habitat assessment, and adaptive monitoring.

What can be learned from formal statistical trend and power analysis, and what are the implications for monitoring design and interpretation of monitoring data?

The panel conducted a set of pilot power analyses to assess the ability of the existing proposed monitoring protocols to generate statistical significance in the face of changes in sturgeon populations of different magnitudes. Details are given in an accompanying document (Peery, 2004), and summarized in the Population Processes section of this report. Not surprisingly, population trends in large, rare, cryptic vertebrates are difficult to demonstrate in an unambiguous way unless the rates of change are large (in this case, roughly halving or doubling the population over a decade). Power can be increased incrementally by increasing sample sizes, the number of sampling locations, and probably by more consistent use of fewer kinds of sampling gear. It is a policy issue whether changes that would increase statistical power are the most valuable use of scarce field resources.

Are there institutional steps that the Missouri River Ecosystem agencies can take to improve coordination and the effectiveness of the monitoring program?

The panel was generally impressed with the level of cooperation and coordination among the people and programs that met with them. All parties agreed that better integration was needed in information systems, and that the working groups to coordinate efforts were still developing effective working procedures. The panel believes that these needs are being addressed. Technical and statistical integration are more challenging, in part simply because of the complexity of both the river system and the many somewhat-related facets of the monitoring programs. Suggested institutional responses are embedded in the text below, and summarized at the end. Perhaps the most important piece is to develop more expertise, possibly either in the form of a standing external technical advisory body or as new staff (or both) in statistical design and trend/power analysis, and to perform regular reviews of whether the design and monitoring data are yielding the information needed to inform policy. An advisory structure could also help the group address genetic technologies and assessments, remote sensing and telemetry, emerging population modeling methods, and related technologies.

CHAPTER 3: CONCEPTUAL MODEL, MONITORING DESIGN AND INFORMATION NEEDS FOR MANAGEMENT.

CONCEPTUAL MODELS, MONITORING, AND INFORMATION NEEDS FOR ADAPTIVE MANAGEMENT

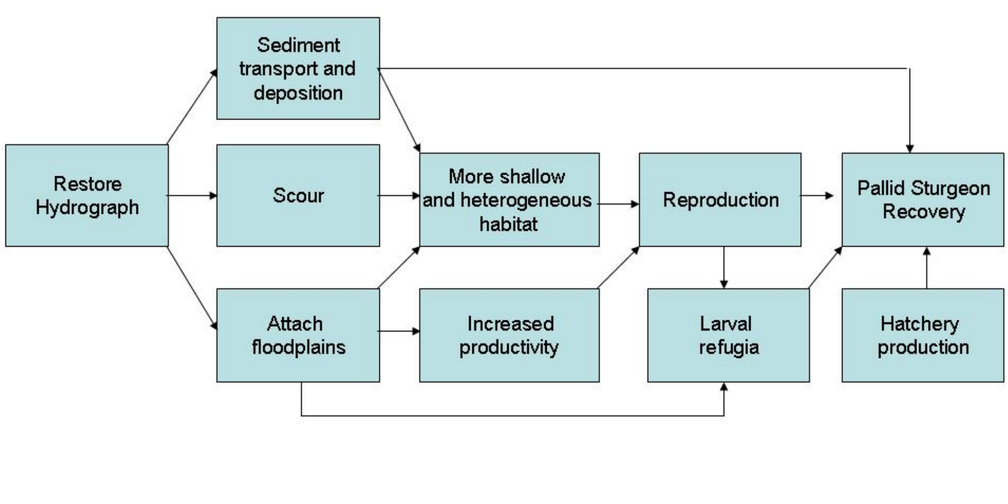
The Pallid Sturgeon monitoring and assessment program is one component of a large and integrated ecosystem restoration effort. Ecosystem-scale restoration programs are inherently complex, and resist simple rule-based policy approaches. Consequently, the management plans for the largest and most ambitious programs call for formal adaptive management, informed by a coordinated regional monitoring strategy. These include the Northwest Forest Plan, the Everglades, the Columbia River Salmon Recovery, the Sierra Nevada Framework, and the Colorado River. There is a widespread recognition in the policy literature that effective management in the face of complexity and uncertainty is best approached as series of incremental decisions, each informed by treating previous decisions as experiments and monitoring outcomes (see, for example, Quinn, 1992; Mintzberg, et al., 1998 for applications to business strategies). Business policy theorists emphasize that well-run organizations typically devote 5-10% of the cost of the project to collecting data on performance indicators and using the information to evaluate outcomes of past decisions. Unfortunately, public environmental and natural resource agencies tend to under-invest in the information needed to formulate effective and responsive public policy (President's Council of Advisors on Science and Technology, 1998).

Experience in large ecosystem restoration initiatives has led to a series of guidelines in how to design monitoring programs to inform effective management (see Busch and Tessler, 1992; Atkinson, et al., 2004 for recent reviews). Adaptive management, a tool for addressing complexity and environmental uncertainty, is now ubiquitous in large environmental programs, and is a stated part of the Missouri River program goals, although definitions and approaches vary considerably. The early literature on adaptive management held that well-designed monitoring programs should validate and parameterize explicit numerical resource-management models (Holling, 1978; Walters, 1986), such as those for the dynamics of marine fisheries or forest pests. Unfortunately, regional management models capable of predicting quantitative outcomes of management alternatives are complex, and have so far proven impractical to construct and validate in huge heterogeneous landscapes such as large rivers, estuaries, and forest ecoregions. Among other problems, effective predictive modeling in large rivers is hampered by the hugely variable time scales between the days-to-weeks of operations models and the years to decades involved in assessing the recovery of long-lived species (Walters, et al., 2000; Geist, 2000).

Instead, the designers of monitoring programs in most ecosystem-scale restoration and adaptive management efforts have built monitoring frameworks around a series of explicit conceptual models. Notable examples include most of the largest and most mature regional restoration efforts in the U.S., including the Northwest Forest Plan (FEMAT, 1993; Noon, et al., 1999; Mulder, et al., 1999; Thom, 2001), the Everglades (Ogden and Davis, 1999), the Sierra Nevada Framework (Manley, et al. 2000), the Columbia River (Geist, et al, 2000), the Sacramento River Delta/San Francisco Bay (Atkinson, et al., 2004), and the Colorado River (Walters, et al., 2000) Successful conceptual models describe the dominant ecosystem processes, stressors, control points, existing and desired endpoints (outcomes to be controlled), and usually legal and institutional mandates and constraints on decision-makers' actions (see Olson, et al., 1994; Busch and Trexler, 2002, Atkinson, et al., 2004, for reviews.)

Formal conceptual models vary in form, but are typically box-and-arrow diagrams (e.g., a cartoon conceptual model for the Missouri River shown in Fig. 4) illustrating a web of causality relating habitat condition, external stressors, management actions, and the dynamics of a number of response variables (rare species, water quality, flooding, fire risk, etc.) of management concern. Both boxes (environmental states) and arrows (causal processes) often contain embedded submodels. Formulating conceptual models that are relatively simple, yet that capture key processes and promote consensus among stakeholders, remains an art.

Figure 4. A conceptual model schematic



Explicit conceptual models serve a number of useful purposes. First and foremost, they force managers to explicitly state the assumptions and priorities underlying management actions. Because the diverse agencies and stakeholders invested in any ecosystem-scale restoration process represent a diverse collection of conceptual models?, this stage is essential to formulating a joint approach to monitoring that is acceptable to the major participants (Lee, 1993, 1999). It is also a first step toward insuring that all of the key variables needed for analysis are in fact being assessed. The literature is replete with examples of expensive, long-term, monitoring efforts that have proven of little use in environmental protection because the putative, "canary in the coal mine" indicator of environmental stress, degradation, or recovery turned out not to be predictive in the way thought, and not enough information on other variables, calibrated to management needs, was collected to interpret the observed outcomes (references omitted to protect the guilty).

Both the EPA EMAP program (Olson, et al., 1994) and the science group for the Northwest Forest Plan (Noon, et al, 1999; Noon in Busch and Trexler, 2002) realized early in the process that conceptual models also provided a powerful approach for clarifying management information needs. They developed conceptual models that specified what parts of operations in a spatially and biologically complex environment are subject to management actions, what predicted outcomes of those actions are, and what indicators should be chosen for monitoring to assess the particular effects of those actions. All authors stress that possible indicators vary in their sensitivity, measurability, amenability to control, and ultimate importance (e.g. threatened and endangered species populations are typically very important to management actions, hard to measure, and may or may not be particularly sensitive to deliberate environmental modifications) leading to a confusing literature on classes of indicators (early warning, control, performance, management among others) which may or may not be important to the participants in the Missouri River process. However, they do provide a framework for treating individual incremental management decisions as experiments, with hypothesized outcomes, measures to test those outcomes, and decision rules.

Explicit conceptual models can help clarify for scientists and field monitoring programs what specific information managers are seeking for particular decisions -- not only on operations or legal or reporting mandates, but also on responses to sudden changes in the system or changes in the policy environment. The conceptual models guiding the assessment were not explicit in the documents we reviewed. We believe that some of the lack of clarity in stated objectives of monitoring, as discussed later in this document, arises in part from the lack of explicit statements of assumptions and hypotheses, which might be expressed as formal, diagrammatic, conceptual models.

The panel recognizes that, although conceptual models are not explicitly described, the Biological Opinion and Biological Assessment have relatively consistent underlying conceptual themes (e.g., Figure 4). To outside observers (e.g., the panel), the Biological Opinion appears more habitat-centric and the BA more population-centric. We do not believe that the habitat and flow-centric conceptual models are incompatible. In fact, the hypotheses that underlie the two views can probably be formally stated, e.g., "Slow-water habitat is important to the fish community and food base for Pallid Sturgeons."

We encourage the participants to examine the conceptual modeling process in some of the big ecosystem restoration initiatives that are further along in the process (Everglades, FEMAT, CALFED, Columbia River, Colorado River) for their approach to conceptual modeling, and to convene a workgroup at an early stage to complete an analogous process for the Missouri River.

The particular nature of the questions asked helps determine the appropriate monitoring designs and statistical analyses. For example, avoiding jeopardy [H0: expected(N_{future}) $\geq N_{today}$] implies somewhat different analyses than assuring recovery [H_0: expected(N_{future}) $\leq N_{today}$], perhaps with rather different approaches to the cost of error in the assessment. Testing whether a time-series is declining (regressions of population counts against time) requires quite different information from testing whether each female on average at least replaces herself ($R_0 > 1$ or $\lambda > 1$, estimated from females' age-specific mortality and fecundity rates), and assessing what habitats sturgeon use to spawn is different from assessing the suitability of each habitat for sturgeon reproduction. Policy as much as scientific imperatives will drive these choices, and the environmental measures collected and indicators used should represent explicitly articulated choices.

The design of the current monitoring regime uses samples stratified by habitat, with approximately equal bend effort in each major segment of the river. Such a survey is capable of providing Missouri River-wide estimates of Pallid Sturgeon status and trends. Stratification by habitat type reflects a conceptual model that is about the properties of habitats, including their occupancy by Pallid Sturgeon. This approach is appropriate for obtaining Missouri River ecosystem-wide estimates of population change, but it is far from the only choice. In particular, research to test hypotheses regarding the factors limiting Pallid Sturgeon might provide more constructive answers for restoring this species. For example, if it were thought that Pallid Sturgeon were particularly dependent on local sites (deep channels, pools, tributaries, floodplains) for feeding or reproduction, sampling could be stratified on those habitats rather than on large river reaches. Alternatively, if in the conceptual model barriers to movement, finding mates, or other life-cycle bottlenecks were the principal events limiting sturgeon success, investigators might spend most of their efforts following individual fish through mark-recapture and/or telemetry, and investigate habitat mostly on the basis of how it intersects sturgeon movement, reproduction, and survival. In this case, individual-based or stochastic demographic analyses might be used more than the current approach, which targets the ability to extrapolate results from habitat subsamples to obtain river-wide estimates of overall population size. If the conceptual model holds that survival, growth, and reproduction are limited by energetics, more effort might go to focused research to estimate local productivity and food stocks. The resulting analytical methods would certainly include fish and community energetics models. One can conceive of foodweb-based conceptual models where the matrix of prey, competitors, and predators (all of which may differ among life stages) are the principal predictors of local sturgeon success, and investigation might include experiment manipulation of other stocks, with follow-up monitoring. Another conceptual model or hypothesis might hold that hybridization and breakdown of the genetic integrity and breeding system of Pallid Sturgeon populations is more threatening than population declines alone. In this case, investment in better understanding differences in spawning requirements, and genetic monitoring (gene chips, sequencing, microsatellite technology, etc.) might be a more important investment than a spatially more-extensive population survey. A conceptual model could also argue that extreme episodic events, perhaps very large spring floods, will be necessary for sturgeon to have a large pulse in recruitment, and effort would be directed more toward estimating the properties and management options of the very rare, very large events from smaller events that can be sampled more regularly.

The panel assumes that the Pallid Sturgeon Monitoring and Assessment Team has considered these alternatives as part of the focused research portfolio, and have clear reasons for following an implicit habitat-based conceptual model, but we do not believe that these choices have been sufficiently formalized, documented, and communicated among the Missouri River and fisheries management communities. The resulting ambiguities certainly contribute substantially to some of the apparent confusion in goals and incoherence in the connections between various parts of the program discussed in the next section.

A final important issue for the Pallid Sturgeon Assessment Team to consider and articulate explicitly as part of the conceptual modeling process is what kinds of answers and certainty policymakers need from population trend analysis. In the Pallid Sturgeon, as with most large, long-lived charismatic vertebrates under ESA protection, the sample sizes needed to detect subtle trends are unachievable in principle (sample sizes would have to be larger than the whole population), and the practical limits to trend detection (declines of several percent per year or more – see the Population Trend section), may be outcomes that have unacceptable policy implications. The power to establish statistical significance of changed Pallid Sturgeon numbers over time can be increased by more intensive sampling and to some extent by other changes in the monitoring design [see Population Trends and the accompanying document on power analysis (Peery, 2004)], presumably at a cost to other targeted, hypothesis driven data collection that could also serve policymakers' information needs.

CHAPTER 4: MONITORING APPROACH

MONITORING APPROACH: RELATING STUDY OBJECTIVES AND CONCEPTUAL FRAMEWORK

A sound conceptual framework with clearly defined hypotheses benefits any monitoring program, particularly when there are multiple goals and when priorities must be set. The following sections provide some discussion and suggestions for ways in which the Pallid Sturgeon Assessment Team can strengthen the monitoring framework and approach.

STUDY OBJECTIVES

Among the most critical components of any study design is developing clearly articulated and obtainable objectives (Lackey and Hubert, 1981; Sokal and Rolff, 2003). Study objectives are formal quantitative statements of project direction which specifically delineate study boundaries and are promulgated through the study design. Failure to work within stated objectives can undermine project success by altering project scope, diluting project-directed effort, affecting analytical assessment, and increasing project costs. Specific hypotheses tested during a study relate directly to individual objectives and provide a detailed outline of the conceptual study design. This program has identified four main objectives which are to document and detect changes in:

- Current and long-term trends in Pallid Sturgeon population abundance, distribution, and habitat use
- Survival, growth, and habitat use of stocked Pallid Sturgeon
- Pallid Sturgeon reproduction and recruitment in the Missouri River
- Current and long-term trends in native Missouri River fish species

CONCEPTUAL FRAMEWORK

As discussed in the previous section, an understandable conceptual framework acceptable to all program participants is critical in developing the study design necessary to accomplish cross-agency objectives. The objectives of this monitoring program are derived from a mix of goals, needs and approaches that range from ecosystem restoration, to documenting population trends in endangered species and the native fish community. While these goals are not mutually exclusive, nevertheless within the confines of this study they have resulted in a mix of differing and often unstated, conceptual approaches, which makes it difficult for participants to formally assess tradeoffs and set priorities. Within this context, the panel felt that the monitoring program would benefit from further development of the conceptual framework and suggest that resolution is needed toward better understanding several issues:

- additional clarification of, and design considerations for the core study objectives, representing activities that will be undertaken throughout the Missouri River System
- separating core study objectives from "additional projects" reflecting local information needs or exploratory investigations
- defining management units and river/habitat classification relative to Pallid Sturgeon population boundaries, and
- re-evaluating gear types and deployment strategies.

Within the current framework, questions of project purpose (i.e., needs and expectations), focus (e.g., species, problem issues), geographic extent, timing and duration, methods (e.g., gear type), analysis approach, logistics, and ultimately costs all must be considered. This is particularly crucial in this study because participating groups may have some differing expectations or interests and project costs will likely require design compromises in order to accomplish shared study objectives in a cost-efficient manner. If all current objectives cannot be reached under resource constraints, the objectives need to be revisited to examine whether prioritization, reduction, and/or elimination in study focus may help solve conflicts. These decisions are difficult to make in the absences of a clear and explicitly stated framework and priorities. Reduction in effort beyond a statistically defensible study design is clearly not acceptable to the monitoring team. Under the existing resource constraints, it may therefore be helpful to focus on objectives most susceptible to quantitative assessment.

Some of the current study design, with its set of objectives, field methodology, and analytical approaches are based on the Benthic Fishes Study (Galat, et al., 2001), which provided an excellent source of on-the-ground sampling experience, including a quantitative template of methods and sampling strategies to draw upon and was a source of data used to initially set some of the effort levels in the initial project design. Feedback from the initial field seasons has influenced approaches to field sampling (i.e., what is both practical and pragmatic), and some preliminary data analysis allowed critical evaluation of the design at an early stage. To the credit of the Pallid Sturgeon Assessment Team and other participants, use of this information at this stage in the design clearly benefits the project. A similar approach is needed throughout all aspects of this monitoring program.

While the current study design indeed benefited from the prior work in the Benthic Fishes Study, it also appears that it is at least partially constrained by its close association with it (i.e., current design is founded in the design employed in and findings of the Benthic Fishes Study). Design constraints also appear to result from differing interests among agencies involved in the project and from the requirements of the Biological Assessment, which encompasses more than simply monitoring populations of Pallid Sturgeon. In particular, there is some lack of parsimony in the design both among the explicit core study objectives (i.e., population monitoring versus habitat monitoring), and also between the core and 'other" implicit competing goals of the study design (i.e., core project versus project wish-lists). It is clear that the Pallid Sturgeon monitoring and assessment program is a large and ambitious effort having multiple goals but many additional research and management questions transcend this effort. To the credit of the participating groups, they have shown strong commitment to the program and devoted large amounts of staff time, effort, and funds to design and execute the sampling program and in some cases, to carry out additional work. However, as with all projects, resources, including staff availability, time, and expertise, are limited.

CORE OBJECTIVES

The panel recommends that two of the four main objectives in the monitoring plan be revisited and that additional statistical expertise would be particularly useful in evaluation and strengthening the study design. The first objective, documenting distributions and population trends in the Pallid Sturgeon, actually contains two different components that suggest fundamentally different design considerations that may not be adequately addressed by the current design. This first objective overtly focuses on issues related to monitoring changes in Pallid Sturgeon population abundance with habitat monitoring embedded in this objective. Effective sampling for rare Pallid Sturgeon in order to assess their abundance is intensive and may require targeting specific habitats where they are more abundant, whereas sampling habitats to develop habitat models requires extensive sampling which includes considerable effort in unused habitats that dilute efforts to obtain sufficient numbers of Pallid Sturgeon for monitoring purposes. These two components need to be delineated as separate objectives requiring substantial discussion to elucidate the conceptual design including specific hypotheses being tested, extent and scope of this work, and analytical approaches that will be used to analyze patterns. Alternative approaches to more intensively following individual fish are discussed in the next section. Moreover, it needs to be recognized that habitat analysis is a major undertaking in its own right, and additional power analyses are prerequisite to determining the level of effort required in any such analysis. Hypotheses should be clearly articulated but they currently appear to be relatively undefined. Approaches to habitat assessment include analyses designed to: 1) understand where Pallid Sturgeon are located (i.e., delineate aggregations for more efficient sampling, 2) delineate limiting habitats for protection and restoration, 3) quantify how changes in habitat may affect the population, or 4) assess how environmental gradients affect the native fish community. Statistical insight is also needed to determine how habitat-specific gear biases can affect any inferences made as habitat models are developed in this critical design stage.

The fourth objective, “current and long-term trends in native Missouri River fish species” was designed with many goals and objectives in mind. It has quite extensive spatial and temporal design elements without clearly articulated hypotheses set a priori.” It breadth makes it difficult to quantitatively evaluate in terms of design at this point. Given that two years of data have already been collected, analyses can be conducted using power analysis to detect trends in the native fish community once specific hypotheses have been proposed. Species under consideration for use in these analyses currently include riverine obligates, perhaps reflecting implicit hypotheses that they represent indicators sensitive to specific hydrodynamic features of rivers for survival, growth, and reproduction. However, this perceived sensitivity may only be relevant for specific types of perturbations. These include, for instance, environmental changes that affect riverine processes that are directly linked to some aspect of various fish species' life histories. The impact of other types of perturbations that affect ecosystem health (e.g., invasive exotic species, hybridization, etc.) should also be evaluated. Guild analyses might also be considered, should distribution of some target organisms be patchy or rare. The panel recognizes that the management teams have undoubtedly considered these issues. However, resulting specific hypotheses are not obvious in the monitoring design documents, and the role and priority of the specific measures in testing management-relevant hypotheses is therefore not clear.

CORE VERSUS ADDITIONAL PROJECTS

The issue of exploratory or local objectives and interests among participating groups, that extend beyond core objectives, can dilute or cause confusion in the design. Some of these "other" objectives may be residual artifacts of the Benthic Fishes Study or "add-ons" arising from jurisdictional or professional interests and needs (USGS 2003). For instance, one such additional project is to "Examine the influence of water temperature and increasing sediment loads on initiation of feeding, growth, and morphological development of post-hatch sturgeon" (USGS 2003). While important, the monitoring plan does not specify why such a project is among the most critical research needs under scenarios of limiting funding. Research and management needs for Pallid Sturgeon were also clearly articulated in a review by the American Fisheries Society where 52 management and research recommendations for managing Pallid Sturgeon in the upper Missouri River were synthesized (e.g., develop a reservoir research and management plan for Lake Sakakawea, determine the impact of introduced fishes on survival and recovery of Pallid Sturgeon) (Webb et al. 2004).

While these additional research needs are important and individually well-conceived, they may detract from developing a cohesive and implementably rigorous study design. Some of the research needs are substantial projects in their own right. However, the core objective of getting good quantitative estimates of rare Pallid Sturgeon abundance may be challenging and costly enough without diverting resources to additional broadly defined objectives, such as "how introduced species affect Pallid Sturgeon" (Webb et al. 2004). The panel suggests that a process be established whereby a research/management working group meets on a yearly basis to review, prioritize, and recommend funding of additional research needs. Under such a scenario, priorities also need to be set for each objective that insure that the most important agreed-upon objectives are sampled at levels high enough to provide statistical rigor in subsequent analyses.

MANAGEMENT UNITS AND HABITAT CLASSIFICATION

In this study design, numerous spatial (i.e., geographic) units operate at various scales that have been used to partition/classify stretches or river or habitat types (see also Bisson, 1981; Hawkins, et al., 1991) for implementing the design and managing the river. It is unclear how some of these habitat delineations affect design strategies (discussed in the Background section), and whether they represent biologically relevant boundaries in the study design. For instance in the current design, there are references to the entire river, segments of river (e.g., segment above Fort Peck Reservoir, Ft. Randal Dam to Gavins Point Dam, etc.), state boundaries, river reaches, sampling units, mesohabitats, microhabitats, etc (see also Background). We recognize that these features serve different purposes.

Prerequisite to implementing a monitoring program is clearly articulating how population trends and habitat relations are ultimately going to be evaluated both spatially and temporally. Agreeing on population boundaries, as determined by genetic analyses and movement studies is paramount to the success of this effort. The number of and boundaries of distinct Pallid Sturgeon populations in the upper river has direct implications on management of the river that needs to be reflected in the study design. Understanding that different river segments vary in their ability to sustain individual segment populations and that dams preclude upstream movement affect how each segment is managed as part of the whole river. Questions that need to be clarified include how declines in one river segment or within a single states jurisdiction will be evaluated, and how various restoration decisions depend upon understanding the population boundaries. Currently, two populations may exist in the upper river (segments 1-4 and segments 5-13) but research describing and delineating these boundaries are not clear. At the whole Missouri River scale, genetic analyses are necessary to verify evolutionarily meaningful population boundaries which then help define a meaningful geography for management.

A key issue affecting the proliferation of management/habitat units is that it directly affects the context under which project success or failure will be judged. There have, for instance, been differing discussions about what constitutes actual populations of Pallid Sturgeon and whether these populations, or perhaps subpopulations within particular smaller river, habitat, or jurisdictional delineations, are actually the overall management units of concern. Presumably, discussion of individual states' management goals need to be couched in the context of overall population viability and therefore these population boundaries need delineation and agreement among agencies. This would include understanding genetic boundaries along with evaluating population parameters for each population. In this regard, stock delineation clearly needs critical resolution at the outset of the project. In practice, of course, the biological boundaries are probably also fuzzy, but it is still worthwhile to try to describe the degree to which the genetic stocks in each area are self-contained versus intermixing with those in other areas.

Conceptually, habitat and management units need to be critically evaluated regarding their influence on the sampling regime and subsequent effects on management goals. Those decisions need peer-review; the success of any recovery effort needs to have these units clearly delineated and objectively critiqued. Given the potential complexity of issues, partners in its design are to be commended for the cohesiveness of their efforts to date.

GEAR TYPE

Sampling gear for fish is highly species, size-class, habitat, and seasonally biased (Ricker, 1975; Beverton and Holt, 1978). Specific gear deployed depends upon study objectives taking into account life history strategies of target species, age-classes of interest, and habitats being utilized. As a result, a wide array of gear types has evolved in the field increasing fishing efficiency and when used in tandem, reducing single gear biases (Hubert 1992). However, use of multiple gear types may also result in less standard sampling, diluted effort, and a decreased ability to compare catches among gear types without undertaking specific cross-validation studies.

In complex riverine habitats such as the Missouri River, many gear types are needed to sample all habitats and species effectively. To the extent it can be accomplished with reasonable gear deployment, it appears that implicit within the current study design is an effort to sample most habitat types in the river, although the information needs and management implications are often not stated explicitly. In this study, reasons for sampling so extensively include minimizing habitat bias in monitoring population size and size structure, monitoring community changes through time, and evaluating habitat use among habitat types as anthropogenic channel changes modify hydraulic and geomorphic conditions in the river. However, decisions need to be clarified as to what type of population indexing will provide the resolution to make sound management decisions. In this regard, it is imperative that sampling gear specifically target the species/community of interest, (age-specific cohorts) within specific habitats when accessible in order to maximize sampling efficiency. At a minimum, sampling needs to adequately index changes in relative abundance over time, not necessarily attain actual measures of abundance (i.e., actual population size).

As a result of competing interests and less-than-specific objectives, the project appears to be partially gear-driven (i.e., effort put toward extensive habitat and species coverage) without full analysis of the intended purpose or effectiveness of some sampling. Gear types employed should first be evaluated with regards to project objectives and analytical usefulness. For this, additional analyses of gear efficiencies and bias should be evaluated using the first two years of sampling. For instance, preliminary data suggest that trawling is inefficient for capturing rare adult Pallid Sturgeon and should be considered for elimination from the Pallid Sturgeon sampling season if it serves no other important purpose in the design. Conversely, additional gear deployment using the most efficient gear in the habitats where Pallid Sturgeon are most abundant could increase sample sizes and thus power to detect changes in the population or to track the fate and reproductive activities of individuals. This is where critical evaluation of study objectives, sampling effort (i.e., costs) and gear types needs close scrutiny. Just because a particular gear can be used in a particular riverine habitat doesn't predetermine its use there. Another consideration is what type of population sampling is adequate for each objective. In particular, objectives first need to be set relative to the type of population monitoring that can adequately address the study objectives such as either indexing or censusing populations of Pallid Sturgeons or other target species.

There is interest expressed in the development and deployment of new gears to capture fish more efficiently. Currently however, the intent of such activities is not clear relative to the overall study objectives which need to guide these endeavors. In this regard, standardized monitoring, at least for achieving the core objective of measuring population changes in Pallid Sturgeon, is more crucial than development and deployment of new gear types. However, with the paucity of young Pallid Sturgeon in current sampling gears, local exploratory development and testing of new gear types/strategies for future incorporation into system-wide core monitoring is encouraged.

TARGETED EFFORT

The current design implicitly partitions sampling into two seasons, though this designation appears not to have arisen from strategically assessing information needs. One sampling season is referred to as the "Pallid Sturgeon Season" and the other referred to as the "Community Season" (see Background). While this design seems to take advantage of the vulnerabilities of different species at different times, it is recommended that the working group specifically recognize these two separate efforts and target species- or year-class- specific sampling in each respective season. In other words, gears and seasons that are effective in catching Pallid Sturgeon could focus efforts for part of the year to increase sample size of sturgeon censuses, rather than attempting to also conduct some community indexing that dilutes sampling effort for Pallid Sturgeon per se. In this regard, it should be clear, that community sampling is an indexing tool and standardized sampling is paramount rather than obtaining measures of absolute abundance. If community sampling is maximized in a designated "community Season", then increased sampling effort will increase inferences that can be made with changes in abundance over time, but not necessarily be a measure of absolute abundance. The committee recommends that the working group more formally acknowledge the two different sampling season and focus effort toward the each respective season to target effort and prioritize each objective to insure that each is obtainable and statistically robust.

RECOMMENDATIONS

1) We recommend that the team initiate a process to develop written conceptual models for the environmental processes addressed by the monitoring program, with goal statements for the overall project and for individual objectives. A particular goal of conceptual modeling should be to clarify objectives and study design by developing specific hypotheses and analyses related to each hypotheses. We strongly recommend that a statistician participate in the process.

2) The team should consider separating habitat monitoring and population monitoring in the first core objective into two separate objectives. For the new habitat monitoring objective, we recommend the team assess the ability of the study design to statistically detect expected and desired changes, using the first two years of data for power and sensitivity analyses.

3) Population boundaries and formal management units for evaluating population trends could be simplified and clarified. We recommend that the team review the habitat, jurisdictional, and geographic units used as management unit surrogates. Where possible, it is desirable to delineate the geographic extent of each population based on genetic analyses and movement data, particularly addressing barriers to movement caused by dams, and how individual river segments function within each population.

4) We recommend establishing a research working group as a subcommittee of the Pallid Sturgeon monitoring and assessment group to annually review project status, assess effectiveness of monitoring , and set (i.e., prioritize) research for additional project needs. An appropriate role for this panel is to provide external peer review and to include an independent external statistician to critically evaluate new projects and proposed design changes.

5) The monitoring program design could be simplified and clarified by separating core monitoring objectives, to be addressed throughout the Missouri River system, from other research projects, methods development, and monitoring for local priorities. A formal review process could then be better used to prioritize the "other" non-core projects in light of funding and logistic constraints.

6) The monitoring program design could be simplified and clarified by more formally recognizing the two sampling seasons: the Pallid Sturgeon Monitoring Season and the Community Season. Ability to detect changes in Pallid Sturgeon populations could be enhanced by targeting habitats that have the highest probabilities of occurrence of Pallid Sturgeon during the Sturgeon Season. Focusing effort on the gear types most effective in those habitats can increase the effectiveness of population trend assessment.

CHAPTER 5: SURVEY DESIGN

DESCRIPTION OF SURVEY DESIGN

Three objectives of the Population Assessment are to provide trend information regarding Pallid Sturgeon abundance and distribution, evaluate the success of the ongoing population augmentation program, and provide information related to dispersal, staging and spawning areas of Pallid Sturgeon (see the Pallid Sturgeon Assessment Team, Draft July 2004, *Long-term Pallid Sturgeon and Associated Fish Community Assessment for the Missouri River and Standardized Guidelines for Sampling and Data Collection*). The sampling design is described in the section on "Sampling strategy" in the protocol document. The current sampling design is a stratified random sampling design consistent with that of the Benthic Fishes Survey (Galat, et al., 2002). The study area is stratified by river segments, which are defined by geographic features. Within each segment (stratum), a sample of river bends is drawn each year. Within each river bend, sub-samples are drawn from each mesohabitat (within macrohabitat) (see Figure 3). This may be repeated with multiple gears for the purpose of comparing gear efficiency.

The fundamental sample unit of the sampling design is the river bend, stratified by river segment. A list of bends is constructed within each river segment at the start of each year (in sampling parlance, this is a finite list frame). This list may change over time, and the numbers assigned to each bend may also change. A fixed number of bends are chosen at random from this list, with a different subset drawn for each of two seasons, the "Sturgeon Season" and "Community Season". The proportion of bends sampled has, heretofore, changed from one year to the next.

In addition to the probability sample of river bends, some bends are always sampled. These bends, for example those with tributary confluences, occur in areas believed to have higher incidence of Pallid Sturgeon. At present, the design provides statistical challenges to using data from "wild" bends in combination with bends sampled as part of the survey, to analyze trends for the populations of interest.

EVALUATION OF THE SURVEY DESIGN

The current design, with some modifications, appears to be a reasonable one for addressing survey goals. Because the design of surveys is a specialized field in statistics, the panel strongly recommends that the assessment team consider creating a statistical advisory group that can provide periodic advice and recommendations. The team should include at least one statistician with expertise in time-series designs and analyses to detect trends in spatially complex populations. As a courtesy to the team, we note that examples of statisticians with this expertise include Scott Overton, Don Stevens, and Scott Urquhart (Oregon State University), and Steve Stehman (SUNY-College of Environmental Sciences and Forestry). The statistical advisory group should consider the following questions: 1) clarification of the statistical universe, 2) clarification of stratification strategy, 3) using the same sample of bends in the two seasons, 4) revisiting the strategy for selecting sample bends, and 5) adaptive sampling design. These are discussed below, mainly for the goal of detecting trends. Other goals, including the assessment of status (see Status section) and understanding habitat requirements (see Habitat section), are not explicitly considered below, but should be reviewed.

CLARIFICATION OF STATISTICAL UNIVERSE

The statistical universe of interest should be clearly defined. We recommend separate trend analysis for each of the two apparently "isolated" pallid populations: the population that occupies segments 1-4 and the population that occupies segments 5-14. The current survey design is consistent with this level of analysis, and the power analysis identified sampling densities needed to detect trends for one of the two Pallid Sturgeon populations (the lower river population). One of our recommendations in the Population Processes section is to focus on three gear types that successfully captured Pallid Sturgeon during the "Sturgeon Season". Consequently, the statistical population the trend detection will become restricted to Pallid Sturgeon that occupy mesohabitats sampled by these gears.

CLARIFICATION OF THE STRATIFICATION STRATEGY

The statistical advisory group may recommend revising the stratification strategy. Stratification can increase the power of a survey design by enhancing the likelihood of sampling areas with fish. Strata are typically defined based on *a priori* information to increase sampling density in high interest areas. Stratum boundaries should be fixed over time (Fancy, 2000) as changing strata in mid-course generally involves losses in usable information and statistical robustness. Thus, if a decision is made to redefine strata, only some of the past two years of data in those segments sampled would be available as part of the trend detection. Careful evaluation should be made of whether the power gains from re-stratifying outweigh the loss of past data. If the decision were made to change stratification strategy, this would be a good time to do so, as some segments have not yet implemented the current protocols. Revisiting the stratification scheme is not unusual in ecosystem-scale restoration initiatives in light of preliminary results, and is probably better done early if it is to be done at all.

The relative merits of continuing with the design stratified on river segment vs. stratifying based on types of habitat occupied by pallid can be quantified. The current stratification based on river segment improves the power of the design mainly if the likelihood of encountering Pallid Sturgeon differs substantially among segments and if the sampling density in segments with a higher incidence of Pallid Sturgeon is increased. Otherwise, stratification on segments is benign. If the past two years of data show that Pallid Sturgeons tend to be sampled in bends within confluence areas, one might alternatively include confluence bends in a separate high-interest stratum. A larger proportion of river bends would then be sampled from the list of high-interest bends than from the list of lower-interest bends. High-interest bends not included in a given year can be sampled apart from the probability sample ("wild"). If habitat differences are not apparent, it may be better not to stratify, but to instead sample the same proportion of bends from the river as a whole. Representing river sections in proportion to their length would permit straightforward later redefinition of geographic boundaries (Overton and McDonald, 1998). A purely random sample would also be simpler to analyze and would be more appropriate for addressing the goal of testing for differences among habitats because sampling would be in direct proportion to habitat availability. Finally, if a future goal will be to relate habitat changes to population trends, then this may be a consideration in stratification.

Finally, it is important for all involved to understand the implications and proper analysis of data from a stratified sampling design. Rather than specifying the number of bends to sample in each stratum, the proportion of bends to sample is specified. To estimate probability of presence for one of the two Pallid Sturgeon populations, we sum presence/absence measured in each bend (zero or one), weighting each value by the inverse of its inclusion probability in the sample. The inclusion probability used in scaling is the proportion of bends sampled from that river segment (Horowitz and Thompson, 1952).

COMPATIBILITY AMONG SEASONS

At present, the design specifies that a different sample of bends is drawn for the Sturgeon and Community Seasons. Unless there is some justification for this that we have overlooked, we would recommend using the same sample of bends. Some consideration of how different gears used in the two seasons influence the universe of inference is also needed.

CONSIDER A REVISITING DESIGN

The statistical advisory group might consider recommending a revisiting schedule. Designs that follow an organized schedule of revisiting units selected as part of a sample have been shown to be more powerful in detecting trends (Urquhard and Kincaid, 1999; Urquhard, et al., 1998; Stevens, 2002). Selecting a larger sample, with sampling over less frequent intervals ensures that the sample is representative and, therefore, also estimates population status reasonably well. Model-based designs can also be helpful. For example, Overton and McDonald (1998) devised a model-based design to detect regional trends in coho salmon in which the trend model fitted between abundances measured over the time interval between visits is the trend estimate, which is then extrapolated to the region/population. Although one can choose a return interval that will not cause a loss of the past 2-y's data, the question remains whether the increase in power of these designs would be significant for such a rare species and whether habitat-related objectives would be sacrificed by such a design (see Habitat section).

CONSIDER ADAPTIVE SAMPLING

The monitoring teams might consider a strategy for increased sampling effort in response to an event. For example, if it is discovered that pallid reproduction is happening in a certain segment, a design that allows increased resolution of sampling within the bend of interest might be of interest. Such an approach can be built into a stratified random design, as demonstrated by Lo, et al. (1997) and others. This approach is well-suited to sampling of populations with a patchy distribution (e.g., shovelnose), and has been used with rare species (Thompson, et al., 1992).

CHAPTER 6: POPULATION DYNAMICS

The future trend in Pallid Sturgeon numbers can be thought of as a compromise between opposite trends: an increasing trend in hatchery juveniles and, in the absence of reproduction, a declining trend in wild adults. Few wild Pallid Sturgeon remain in the Missouri River between Ft. Peck Dam and the Mississippi confluence, and these are nearly all adults. Although an optimistic future would see stocking contribute to a stable or increasing adult population, it is possible that the "survey method" (*sensu* Taylor and Gerrodette 1993) will only have the power (roughly 0.8) needed to detect trends greater than about 5% per year in the local probabilities of occurrence after ten years if sampling effort is doubled (see the Population Processes section of this report and the accompanying technical report by Peery). Thus detection level would of course change with changes in study methods.

The "demographic method" is often a more powerful alternative to population time-series analysis in rare species, and is used in conservation biology to predict population changes over time (Taylor and Gerrodette, 1993). This approach estimates life history parameters from recapture information for a sample of individual fish, and uses these to solve for the discrete population growth rate, λ, (or alternatively, the net reproductive rate R_0), which exceeds 1 in a growing population. Life history parameters include survival rates, fecundity, and age (or size) at maturity. For open populations, migration between the two populations in the Missouri River and the population in the Mississippi (and perhaps local aggregations within those populations) would also be estimated. The demographic method is feasible even with a small population, and an even smaller sample of individuals captured during the assessment. It does, however, depend upon being able to estimate effective reproductive output of females, which could be problematic when applied to Missouri River Pallid Sturgeons.

INDIVIDUAL-BASED MONITORING (TELEMETRY)

Under the current protocol, all Pallid Sturgeon (juvenile and adult) sampled as part of the Population Assessment are tagged with individually identifiable marks. If it can be done without increasing mortality risk, we recommend telemetry and tracking of all adult Pallid Sturgeon. This will support the use of a demographic approach to estimate population trends via estimation of vital rates, including survival and inter-spawning interval. A second objective furthered by telemetry is to characterize habitat use (see Habitat section).

Telemetry of adults captured as part of the Population Assessment would allow individuals to be relocated and support several of the Population Assessment's goals. Adult survival can be estimated by analyzing how many individuals can be relocated from year to year, and does not require capturing individuals. The proportion of adult females ready to spawn each year estimates the time interval between spawning efforts for females, another vital rate needed to estimate population growth rate using a population model. This is estimated by recapturing individual females outfitted with telemeters and "staging" their eggs to see whether they will be ready to spawn in the upcoming spring. Annual collection of female adults can provide staging information using minimally-invasive methods. Because female Pallid Sturgeon are known to be sensitive to handling, it is important to use minimally-invasive methods and to conduct staging in late fall to avoid harming females or retarding egg development. During the spawning season, almost any new information (for example, co-occurrence of the two sturgeon species, observing the deposition, movement, and/or depredation of eggs) would help to understand factors that influence recruitment. Passive fixed receivers along the river might be used to efficiently track individuals, and would be very useful in estimating migration rates at the system's boundaries.

POPULATION MODELING APPROACH

Population models can be used to predict trends under different scenarios of habitat and flow. The vital rates estimated above from telemetered individuals and recaptures would be used as parameter values in the models. Various types of population models can be used, including stage- or age-based models or individual-based models. Because abundances are small, and information will be collected on individual fishes, an individual-based approach would be appropriate (DeAngelis and Gross, 1992). For example, an individual-based population model has been used to evaluate the effects of habitat fragmentation, entrainment mortality, and other risks on white sturgeon (Jager, et al., 2000). Methods are also available to construct stochastic age- (e.g., Leslie matrix) or stage- specific population growth models for rare, long-lived fish (e.g., Cisneros, et al., 1997).

RECOMMENDATIONS:

1) Consider telemetering all adult Pallid Sturgeon captured. Use telemetry to estimate demographic parameters and better understand spawning.

2) Consider the demographic approach (i.e., population modeling) as an alternative approach to estimating population growth rates (i.e., trends).

HABITAT

One of the goals of the Population Assessment is to document the distribution and habitat use of Pallid Sturgeon (and surrogate species) throughout the Missouri River system. As is true for other declining species of sturgeon, recruitment is the broken link in the life cycle of Pallid Sturgeon. In a "best-case" scenario, the limiting factor would turn out to be simply the number of adult spawners: a problem easily remedied by stocking. Unfortunately, experience with other declining sturgeon species suggests that the bottleneck occurs during the incubation or fry lifestages (e.g., Kootenai R. white sturgeon, Paragamian and Wakkinen, 2002). One hypothesis to explain the lack of natural recruitment is that the channelized Missouri River lacks habitat to support spawning, incubation or fry. For this reason, it is important to elucidate the habitat requirements for spawning and early development. We therefore recommend that habitat investigations focus on spawning and early lifestages of Pallid Sturgeon, and ensure that enough effort is dedicated to these lifestages.

The current survey design includes a habitat component that identifies the habitat where pallids are collected. A sub-sample is drawn from each meso-within-macrohabitats that occurs in a sample bend. A strength of the current design is that it samples all habitat types. This is important because habitat models are more robust when developed from a comprehensive survey that provides information on where fish are absent, as well as where they occur. Thus, if future efforts focus on fewer gears during the Sturgeon Season, the past two-years' data will represent a valuable baseline resource for addressing questions about spawning habitat.

A weakness of the protocol is that hypotheses related to habitat are often not formally stated or accompanied by an approach for statistical testing or modeling. We recommend formal statement of hypothesis to be tested with respect to habitat. For example, "Does pallid spawning preferentially occur in ____ (tributaries, confluence areas)? ", "Does incubation preferentially take place in _____ (areas on the downstream end of islands)?", or simply, "Are there differences among mesohabitats used for spawning?" Similar hypotheses should be specified for egg incubation, larva and other early life stages. This objective should probably focus on spatial variation in relative abundance (status), rather than spatial variation in trends. A logistic regression model for probability of occurrence with mesohabitats (within macrohabitats?) as covariates can be used to quantify habitat preference. Power analysis using preliminary data can be used to determine how well the survey design will be able to detect differences among habitats.

As with the trend detection question, the survey method has some limitations. For example, not all habitats are sampled and gear types vary in their ability to catch fish. Telemetry is a complementary approach that will help to alleviate this problem and provide necessary information on habitat use by Pallid Sturgeon. This, in turn, can be linked with habitat data for a more complete picture. Determining what Pallid Sturgeon require to successfully reproduce in the wild is critical for long-term recovery. A combination of the survey, telemetry, and targeted studies can be used to answer this important question, although an integrated statistical analysis could be complex, and should be reviewed by qualified statistical advisors before full deployment.

RECOMMENDATIONS:

1) Focus habitat study on spawning and early lifestages of Pallid Sturgeon. Spawning and incubation occur during the Sturgeon Season, but early lifestages post-incubation occur during the Community Season.

2) Define the hypothesis to be tested with respect to habitat and specify how survey and telemetry data will be used to address the hypothesis.

3) Conduct a power analysis to evaluate the ability of the survey to detect habitat preferences, if they exist.

STATUS – ESTIMATION OF POPULATION SIZES

One goal of the Population Assessment is to assess the status (i.e., abundance) of the two pallid populations. This will provide a baseline against which future trends can be compared. Mark-recapture techniques are commonly used to obtain this information. We understand that efforts have been made in the past to quantify population sizes and confidence bounds, with better success in segments 1-4 than in the remaining segments. We recommend a review of the survey design to ensure that status can be obtained. For example, if individuals are tagged during the assessment, it may be possible to use recapture information.

RECOMMENDATION:

1) We recommend a review of the survey design to ensure that status can be obtained.

HYBRIDIZATION WITH SHOVELNOSE STURGEON

The appearance of pallid-shovelnose hybrids has led to concern that the Pallid Sturgeon may lose its genetic identity (Carlson, et al., 1985). Hybridization between the pallid and Shovelnose Sturgeons was first reported by Carlson et al. (1985) in the lower Missouri River (RM 16-534) and in the Mississippi River between RM 341 and 852. Hybrids occurred at roughly the same frequency as Pallid Sturgeon in the Carlson et al. study, suggesting that hybridization may be a significant issue. Hybridization appears to be more common in the Mississippi River and lower reaches of the Missouri than in the upper Missouri River.

There is a clinal gradient in physical characteristics that suggests that backcrossing of hybrids is occurring as well (Wills, et al., 2002). The fertility of hybrids and backcrossed individuals is not yet known, but all hybrids captured in the Carlson et al. study were female, suggesting that female hybrids may have higher viability than males. At the time of the Carlson study, electrophoretic analysis at 37 loci failed to distinguish the two species, let alone hybrids. However, individuals identified as hybrids were found to be intermediate in morphometric and meristic characteristics, including size. Like Pallid Sturgeon, their diets included a significantly higher proportion of fish than Shovelnose Sturgeon did. It is not known (but should be easy to determine) whether hybrids are the result of male Pallid Sturgeon fertilizing shovelnose eggs, or vice-versa, or both.

MORPHOMETRIC AND MERISTIC CHARACTERISTICS

Although pallid and Shovelnose Sturgeon differ morphologically, smaller specimens are harder to distinguish than adults (Bernie Kuhajda, University of Alabama, personal communication). Mayden and Kuhajda (1996) discuss morphological differences of these two species and Alabama sturgeon and allometric changes with growth. Wills et al. (2002) were able to discriminate the two species about 90% of the time for sturgeons > 434 mm. Although the ability to distinguish the species using character indices has improved, the rarity of historical type specimens has been a problem. This can be prevented in future by photographing the top and bottom of the head with a ruler.

GENETICS

The separate genetic identity of pallid and Shovelnose Sturgeon populations has been confirmed by microsatellite analysis of nuclear DNA (Tranah et al. 2001) and in several studies of mitochondrial DNA. Campton et al. (2000) found differences in mtDNA with 80% discrimination, and Simons et al. (2001) found 1 in 1300 base pair (bp) difference in mitochondrial control loop D. The idea that the two *Scaphirhynchus* species (and also the Alabama sturgeon) were not genetically distinct comes from a forensic test that failed to find differences among caviar from the three species. This test was applied by FWS to a section of genome that has been sequenced (350 bp on the mitochondrial cytochrome B gene). This section is a variable region in the genus *Acipenser*, but apparently not among *Scaphirhynchus* species.

The main value of genetic research to distinguish the species is to improve our ability to discriminate individuals in the field, for example smaller fish or eggs (caviar). Researchers are searching for new regions of mtDNA to sequence that better discriminate among the *Scaphirhynchus* species. For example, Straughan et al. (2002) are finding new discriminating regions of mtDNA. Microsatellites (nuclear DNA) are also able to discriminate the two species. Heist and Shrey (in prep.) and others have done research to better detect species differences using nuclear DNA. Although the ability to discriminate a single individual is not perfect, it meets the standard of 95% certainty.

New technologies, such as "gene chips", to test for genetic composition of populations and/or interspecific differences are constantly improving and declining in cost, and have now been deployed to differentiate species, even at the larval level, in a variety of taxa (e.g. marine intertidal invertebrates, Palumbi, et al., 2003). The monitoring teams, perhaps through a technical advisory group, should explore potential applications to Missouri River sturgeons.

HYBRIDIZATION AS AN ALLEE EFFECT

Hybridization is one Allee effect – i.e., as the abundance of pallid adults declines (or shovelnose increases) chances of hybrid crosses increase. This is one reason for keeping track of the genetic status of individuals caught as part of the survey. In addition, telemetry of adults during spawning can indicate the co-occurrence of shovelnose and pallid adults in spawning aggregations.

RECOMMENDATIONS:

1) To better understand overlap and separation in spawning time and habitat, telemeter adult shovelnose and track them during the spawning season.

2) Consider a directed study to determine whether both hybrid crosses are equally viable (e.g., male Pallid Sturgeon fertilizing shovelnose eggs, or vice-versa).

3) Consider developing a “gene-chip” to describe individual genetics.

4) Save a voucher genetic specimen for each individual tested.

5) Develop a protocol for providing feedback from genetic tests on sampled pallids to the survey database prior to analysis. Ensure that there are appropriate linkages between individual genetic data and the survey data though a unique individual identifier.

6) Refine the documentation of the survey design to specify how hybrids will be defined and treated in the Population Assessment, both in the analysis of population trends and habitat use.

CHAPTER 7: POPULATION PROCESSES

TREND ANALYSIS – INTERPRETATION OF POWER ANALYSIS

APPROACH AND ASSUMPTIONS

For endangered species in large ecosystems, it is particularly important to distinguish abundance trends in the face of scarce occurrence data that is highly variable in space in time. Under such scenarios, the ability to detect a change is confounded by a high noise to signal ratio (e.g., Thompson, et al., 1998). The power analysis conducted as part of the review is particularly appropriate because it makes use of (1) existing data, (2) models variances associated with survey parameters (i.e., species, gear, and segment), and (3) utilizes this variance to determine the probability of detecting a range of signal strengths (rates of sturgeon decline) within the expected noise introduced by natural and sampling sources of error. In addition, the power analysis represents a prudent prospective view towards optimizing sampling design elements within the framework of the Pallid Sturgeon recovery program's goals and hypotheses.

The power analysis addressed the following questions:

1) How much sampling effort is needed to detect population declines?
2) What levels of change can be detected in different timeframes?
3) What rates of decline can be reasonably detected?
4) Can rates of decline be detected at scales smaller than the entire Missouri River?

Important assumptions of this analysis include:

1) Random sampling
2) Gear type treated as a fixed effect in modeling variance
3) A single year of data is representative of future years; i.e., interannual variance is negligible (necessitated by having only a single year of data for resampling)
4) Simulated population decline rate over years follows an exponential decay model (i.e., there are no strong density-dependent effects)
5) Incidence (local presence/absence) data is representative of increasing or decreasing population trends
6) Relevant Type I error rate (α=0.10) and effect size
7) Trends in Pallid Sturgeon occurrences across all life history types are reflective of true population trends

The monitoring program has undertaken stringent measures to ensure that bend and site selection incorporates random selection procedures. Thus, random sampling can be assumed. The three gear types (gill and trammel nets and otter trawl) are known to have differing efficiencies for species, size, and behavior (see further discussion below). Yet, because catch was analyzed as occurrence (presence/absence) data, the differences between gear efficiency were minimized and all gears were combined in the power analysis of Pallid Sturgeon. We note that the power to detect trends in abundance is usually greater than the power to detect trends in occurrence (Strayer, 1999), but it requires a higher encounter rate with Pallid Sturgeon individuals or individual Pallid Sturgeons? than is presently observed in the Missouri River. Because captures of multiple Pallid Sturgeon are rare, there is little practical difference between the results of power analysis on occurrence vs. census numbers for pallids, and the distribution properties and internal consistency of assessing results by occurrence probably make that analysis more reliable for other species.

Results of the power analysis should be conditioned by limited assumptions imposed by a single-year study conducted in only 5 of 14 Missouri River segments. Climatic conditions (e.g., flow and temperature) can vary substantially on an inter-annual basis and this probably affects gear efficiency and sturgeon behaviors and their availability to gear throughout the Missouri River. The effect of this limiting assumption would suggest that the approach of the current power analysis (i.e., simulated variance through resampling data weighted by a hypothesized increase or decline) may provide a positive bias towards detecting trends because interannual environmental variance is necessarily under-represented in any single year's study (also see Peery, 2004).

The shape of expected rates of change in occurrence in Missouri River Pallid Sturgeon is unknown and in the face of this uncertainty, there is theoretical justification to apply an exponential model (e.g., Boreman, 1997; Secor, et al., 2000; Gross, et al., 2001). Still, this model assumes no depensatory or compensatory responses (density-dependent feedback). Density-dependence might be expected should the population decline below a minimum viable population size (i.e., the Allee effect) or should Pallid Sturgeon compete with shovelnose or hatchery released sturgeon for limited habitat resources. Additionally, population growth in sturgeons and other fecund temperate fishes are expected to occur through the formation of strong year classes, which are periodic or episodic in their occurrence (Nilo, et al., 1997; Jager, et al., 2001). This means that in most years recruitment will fail and can approach nil, and specifies that population trends for long-lived species like sturgeon must be evaluated over decades rather than years (Secor and Waldman, 1999).

The use of incidence data (i.e., % occurrence) was justified given the scarcity of gear deployments expected to capture multiple Pallid Sturgeons. Indeed, for the sample set used in the power analysis, no multiple captures of pallids occurred in any single gear deployment. Pallid Sturgeon and other sturgeons are known to aggregate during certain seasons (Bain, 1997; Bramblett and White, 2001) and occurrence data could discount trends in abundance if fish are patchily distributed (see also Z. Peery's scenario of a 10% decline in abundance without changing rate of incidence, p. 13, attached report, Peery, 2004). Thus, incidence data may not fully represent abundance trends. Still, incidence data is expected to provide suitable and appropriate variance functions in estimating trends for rare species. For instance, inter-annual variances in catch per unit effort (CPUE) driven by a single aggregation of sturgeon may not be as representative as incidence data distributed across many aggregations of fish. Further, the lack of multiple recaptures per single gear deployment for Pallid Sturgeon indicates that little information is being lost in considering incidence versus CPUE data.

The level of α is stipulated by management concerns. The current power analysis specified a two -tailed test, a Type 1 error rate (α) of 10%, and effect sizes ranging 1%, 3% and 5% per year over a ten-year period. Thus, the likelihood to accept H_A – that a population is declining or increasing – when it was in fact not was stipulated at 10%. Here, the two-tailed test was specified because there is interest in detecting both decreasing and increasing trends. A sensitivity of 10% was justified based upon the small sample size and a guess that 90% certainty would be acceptable for management purposes.

Small effect sizes over a moderately long interval are appropriate given the risk of extinction and life history considerations for this species (Gross, et al., 2001; Jager, et al., 2001; Secor, et al., 2001). For instance, 1%, 3%, and 5% annual declines over 10 years translates respectively to an absolute decline of 9%, 24%, and 37%. Further, under a scenario of negligible recruitment, natural mortality of adults is expected to range between 1% and 8% (Boreman, 1997; Krentz, 2000; Gross, et al., 2001). Thus, the tested effect sizes are relevant to detecting declining abundances due to senescence alone over a period of a Pallid Sturgeon generation or less. In the power analysis, all Pallid Sturgeon were combined, regardless of their classification as juvenile, adult, hatchery fish, population membership. In addition, there is some chance that hybrid shovelnose x Pallid Sturgeon may have been misidentified as Pallid Sturgeon. Consequences of this assumption to recovery goals are discussed further below and in the preceding section.

TRENDS IN MISSOURI RIVER PALLID STURGEON (ALSO SEE PEERY 2004)

In 2003, a total of 15 Pallid Sturgeons were captured in the five randomly sampled segments of the Missouri River (Table 8). These were distributed between gillnet (3), trammel net (9), and bottom trawl (3) gears. No other gear types (hoop nets, fyke nets, beam trawls or seines) captured Pallid Sturgeon.

Table 8. Missouri River pallid and shovelnose captures during 2003 used in the power analysis.

Segment	Gill Net	Trammel Net	Otter Trawl	Hoop Net
Pallid Sturgeon				
5	1 (0.059)	3 (0.029)	No effort	0
6	0 (0)	2 (0.013)	No effort	0
9	1 (0.017)	0 (0)	1 (0.011)	0
13	1 (0.008)	2 (0.016)	1 (0.009)	0
14	No effort	2 (0.014)	1 (0.01)	0
All Segments	3 (0.013)	9 (0.014)	3 (0.01)	0
Adult Shovelnose Sturgeon				
5	9(0.53)	25(0.24)	No Effort	0(0)
6	2(0.10)	240.16)	No Effort	0(0)
9	59(0.98)	49(0.36)	44(0.48)	31(0.21)
13	111(0.84)	62(0.50)	58(0.54)	18(0.15)
14	No effort	70(0.47)	43(0.46)	6(0.04)
All Segments	181(0.79)	230(0.35)	145(0.46)	55(0.10)
Juvenile Shovelnose Sturgeon				
9	49(0.82)	32(0.24)	26(0.28)	15(0.10)
13	840.64)	40(0.33)	47(0.44)	6(0.04)
14	No effort	55(0.37)	36(0.36)	4(0.03)
All Segments	133(0.70)	127(0.31)	109(0.36)	25(0.06)

In the modeled power analysis, M. Z. Peery considered only segment (input data n=5 segments; modeled output=10 segments), bend (n=6, 12, 18, and 24) and subsample (n=12, 24, and 36). Macro- and meso-habitats were not considered explicitly. Rather, these strata were pooled into the category of subsample (Table 5; Peery 2004, Table 1). Some inferences about gear influence can be gleaned from the raw data, which indicated that across segments gill and trammel nets were similarly selective for Pallid Sturgeons; otter trawl had somewhat diminished efficiency (Table 8). The data did not support inferences on the effects of macro- or meso-habitats on sturgeon catch or incidence rates.

For the current minimum modeled sampling effort (6 bends per segment and 12 subsamples per bend), which corresponds approximately to the system-wide base effort level envisioned in the monitoring plan, the power to detect declines in Pallid Sturgeon in all sampled segments was low across all rates of population change. Power varied between 8% for a ± 1% per year decadal change to 39% for a ± 5% per year decadal change. Power changed more rapidly by increasing sampling of bends per segment in comparison to subsamples per bend (see Peery 2004, Table 5, Figure 1). To detect a change of ± 3% a two-fold increase over baseline (6 bends, 12 subsamples) in number of bends resulted in a 62% gain in power, whereas a two-fold increase in subsamples resulted in only a 33% gain in power. Under the same baseline, 2-fold changes in effect size (±3% to ±6%) resulted in a 162% gain in power. Increasing the duration (10 to 20 years) over which a trend is detected resulted in a 252 % gain in power.

A single power analysis was performed on gear types for the scenario of 3% annual change, 6 bends, and 12 subsamples. Under this baseline, power was highest for gill net (22%), and lower for trammel net (16%) and otter trawl (18%). Gill net deployments were substantially less in 2003 than trammel net or otter trawl, suggesting that power gains are possible with increased deployment of gill nets.

To evaluate whether trends for Pallid Sturgeon could be evaluated at spatial scales smaller than the Missouri River ecosystem, a power analysis of combined segments 5 and 6 was conducted. In these segments, effort had been deliberately higher than stipulated in the protocol (R. Klumb, pers. comm.). As expected, the segment power analysis showed lower ability to detect trends in comparison to the entire Missouri River analysis. At ± 5% annual change, 12 bends per segment, and 24 subsamples per bend, < 30% power was achieved. In contrast, under this same baseline sampling conditions, power to detect a ± 3% change for adult shovelnose was ~80%, indicating that it is feasible to detect trends in this with moderate increases in sampling intensity.

The overall result of the power analysis indicates that increased sampling effort in the program would yield important improvements in the ability to detect population changes in Pallid Sturgeon. While bend sampling intensity had only moderate effects on power in comparison to effect size and duration of effect, it is noteworthy that increasing effort to 18 bends per segment resulted in moderately high power (~80%) to detect a ± 5% change. In conjunction with an increase to 24 subsamples per bend, an increase to 18 bends per segment also provided moderate power (~60%) to detect a ± 3% change. Further, power curves showed a fairly linear rate of increase with increasing number of bends per segment, suggesting that increasing bends sampled above 18 would result in proportionally increased power. For instance, 24 bends per segment at 24 subsamples per bend, would yield ~80% power to detect a ± 3%. Determining trends for combined segments, such as segments 5 and 6 combined may be feasible, but to obtain sufficient power sample size needs to be increased several fold by increasing number of bends, subsamples, or both.

TRENDS IN MISSOURI RIVER COMMUNITY INDICATOR SPECIES

The Pallid Sturgeon Recovery Plan seeks to make use of a diverse assemblage of Missouri River demersal ichthyofauna to evaluate sturgeon vs. habitat relations, which are expected from an overall concept for habitat improvements and Pallid Sturgeon recovery. The principal assumption is that habitat and ecosystem change might similarly affect community indicator species and Pallid Sturgeon. Although no single species can be said to serve as a surrogate species, based upon evidence in hand, investigations of a suite of species using the same or similar habitats over parts of their life histories or among seasons may be a prudent approach, given the scarcity of Pallid Sturgeon.

Shovelnose Sturgeon were chosen to represent the demersal fish community and exhibit some similarities to Pallid Sturgeon. For instance, behavior and susceptibility to gear and overlap in habitat resources for juvenile Pallid Sturgeon and all life history stages of Shovelnose Sturgeon. Further in some parts of the Missouri River, incidence of hybridization is an important concern, which could be influenced by an increased ratio of shovelnose to Pallid Sturgeon (Tranah, et al., 2001; see also the discussion above). Thus, it may be equally important to detect trends in shovelnose to evaluate threats to Pallid Sturgeon recovery imposed by hybridization. Still, important differences occur in the distribution of adults, migration and spawning behaviors, and expected population structure that merit caution in ascribing similar abundance trends between these two sturgeon species (e.g., Bramblett and White, 2001; Kynard, et al., 2002). Further, the disproportionate increase of Shovelnose Sturgeon in comparison to pallids could lead to spawning interference, increased hybridization and population depensation (see Population Dynamics). Sturgeon species are commonly sympatric in large rivers, but do not necessarily respond in synchrony to ecosystem change. For instance, in the Hudson River Shortnose Sturgeon abundance has increased four-fold during the past 20 years, while Atlantic Sturgeon abundances have declined (Peterson, et al., 2000; Secor, et al., 2001). Similarly, there is evidence in the lower Missouri River that shovelnose has increased their abundance in comparison to Pallid Sturgeon (Tranah, et al., 2001). Thus, without firm evidence on how sympatric sturgeon species interact, caution should be used in inferring that abundance trends of sympatric sturgeon species will be synchronous with habitat and ecosystem change.

Because there was interest in the ability to detect recruitment changes, Shovelnose Sturgeon power analyses were done separately for juvenile (TL<500 mm) and adult Shovelnose Sturgeon. Adult shovelnose were commonly encountered across all segments in gill and trammel nets and otter trawl gears (Table 8) and less frequently captured in hoop nets. Juvenile shovelnose were captured only in segments 9, 13, and 14, but similar to adults were selectively captured with gill and trammel nets and otter trawl gears in comparison to hoop nets. Gill nets were particularly efficient in capturing young and adult shovelnose in comparison to other gear types.

For the current minimum modeled sampling effort (6 bends per segment and 12 subsamples per bend), the power to detect declines in Shovelnose Sturgeon (juveniles and adults) across all sampled segments was higher than for pallids ranging between 55 to 60% for a ± 1% change to 100% for a ± 3% or ± 5% change. Because power was already high at baseline levels for shovelnose, increasing sampling effort, effect size, or duration of detection, only affected power substantially if trying to detect a ± 1% change (Peery 2004, Table 5).

Overall, the power analysis indicated that sufficient sampling effort already exists to detect small changes in status of both juvenile and adult stages of shovelnose over a ten year period. Unlike Pallid Sturgeon, much greater resolution in change (i.e., ± 1%) is feasible with small increases in sampling intensity. Although Shovelnose Sturgeon catches were treated similarly to Pallid Sturgeon catches (as incidence data), in the future, it may be more appropriate to consider using catch per unit effort data for shovelnose and other community species. In initial research conducted by Z. Peery, standard transformations of catch data were unsuccessful, but this statistical issue merits additional analysis.

POPULATION PROCESSES -- FINDINGS

EFFORT AND SAMPLING DOMAIN

The sensitivity analysis for Pallid Sturgeon indicated that moderate but important gains can be made in detecting population changes through increased sampling effort. Further, increasing the number of bends per sample had a larger effect on power than increasing the number of sub-samples per bend, suggesting a higher rate of covariance among sub-samples, as would be expected. In practice, the power advantage of spreading out samples geographically has to be balanced against the increased logistical complexity and cost of visiting more bends. A power curve analysis on sampling effort (see Peery 2004) confirmed these trends and indicated that for Pallid Sturgeon, power increased in proportion with increased sampling effort. Changing the study duration or effect size resulted in greater gains in the power to detect declines. But a large increase in either of these may be undesirable given the endangered status of Pallid Sturgeon and the priority on near term action related to relatively small changes in population status.

GEAR ISSUES

Initial survey data indicated that gill and trammel nets were the most representative gear types in showing future abundance trends. Experience with multiple gear types in the Missouri River and general experiences from other sturgeon monitoring programs (Table 9) jibe with the expectation that set gill and trammel nets are among the most effective gears for indexing abundance trends for sturgeons. Sturgeons' general "snout-first" rooting behavior, long bodies and scutes, and sluggish behaviors all contribute to their effective ensnarement in passive entanglement gears. Interestingly, recent comparisons of experimental gill nets with trammel nets for Shortnose Sturgeon in the Altamah River (D. Peterson, Univ. GA, pers. comm.) suggest that trammel nets may sample all available size classes of sturgeon. If such is the case without loss of overall gear efficiency, it might suggest trammel nets are a superior gear for sturgeons. Trawls are problematic ways to assess sturgeons (Grogan and Boreman, 1998; Secor, et al., 2001; Federal Register, 2002) due to concerns of low and variable efficiency. Small trawls are typically poor at sampling larger fish and given their noise and motion, sturgeons may be effective at avoiding them. Still, small sturgeons are frequently captured, indicating that trawls may be an effective means for collecting biological information on juvenile Pallid Sturgeon and on all stages of Shovelnose Sturgeon (e.g., Levin, 1995). The same could be said of trap nets, which are more effective for small juvenile sturgeons (Table 9). Set lines are increasingly gaining popularity as a means to sample larger piscivorous sturgeons, yet this is a fundamentally different gear type relying on attraction to bait. It is doubtful whether indices of abundance can be based upon set lines and other such gears that select for specific behaviors (i.e., hungry sturgeon swimming down stream of the bait plume).

Table 9. Comparison of gear types and criteria for their use in Pallid Sturgeon sampling. General assessments based upon literature review of three recent sturgeon publications: Gershanovich and Smith 1995; Birstein et al. 1997; and Van Winkle et al. 2003.

	Gill Nets	Trammel Nets	Trawls Otter/Beam	Seine	Set lines	Hoop/ Fyke Net
# MR Pallids, 2003	3	9	3	0	----	0
Power : 6 bends, 12 sub-samples and 3% change	22%	16%	18%	0	----	0
Risk of Stress or Lethal Responses	Moderate risk: Little stress if deployed properly; high temperatures and long soaks stressful – see Pallid SOP	Moderate risk: Little stress if deployed properly; high temperatures and long soaks stressful – see Pallid SOP; may be less stressful than gill nets: not all fish are "gilled"	Moderate risk. Little stress if deployed properly; high temperatures and long tows stressful – see Pallid SOP; can promote "net-feeding."	Little risk and stress	Unknown risk. Stress likely related to soak time and hook type. Circle hooks should be part of SOP. Merits additional study.	Little risk and stress if frequently checked – see Pallid SOP; can promote "net feeding" on small sturgeons
Collects representative and quantitative data	Yes, but size selective, which should be corrected; catchability varies with environmental conditions. Can be coupled effectively with mark-recapture studies.	Yes, and potentially less size selective than gill nets; catchability can be estimated if paired with gill net deployments. Can be coupled effectively with mark-recapture studies.	Doubtful. Small size of gear and site specificity of deployment requirements indicates that gear may only effectively sample juveniles. Can be used to expand CPUE to areal abundances if catchability is known.	No. Sturgeons rarely if ever captured in shoal habitats with beach seines.	No. Good for getting fish for biological attributes, but depends on appetite, deployment location, etc.	Uncertain/Doubtful. Can be effective in specific flow/river conditions for trapping juveniles.

	Gill Nets	Trammel Nets	Trawls Otter/Beam	Seine	Set lines	Hoop/ Fyke Net
Consistent in deployment	Yes with caveats: Needs stretch of river with certain depth, current conditions. Such conditions are common throughout MR and current design is appropriate in deploying this gear in bends. Debris can be an issue.	Yes with caveats: Needs stretch of river with certain depth, current conditions. Such conditions are common throughout MR and current design is appropriate in deploying this gear in bends. Debris can be an issue.	Doubtful. Changing bathymetry and snags indicate that trawling will be difficult to standardize across MR segments and bends.	Doubtful. Habitats conducive for seine deployment are often ephemeral and adjacent bathymetry and bottom type will affect deployment	No. Only certain sites conducive for baited hook deployment.	Doubtful. Changing flow conditions and littoral habitats will have large influence on where gear can be deployed and its effectiveness.
Cost effective	High. Passive gear; when longer soaks are permitted effort can be high.	High. Passive gear; when longer soaks are permitted effort can be high. Net repair can be laborious.	Moderate. Active gear necessitating more labor in deployment. Snags and lost trawls can be problem.	Moderate. Very low cost; active gear, and labor can be substantial.	High. Passive gear; more effective with longer soaks and careful site selection.	High. Passive gear; more effective if set up times are low and soak times are relatively long.
Targeted Biological Samples	Yes. Mesh sizes select for specific sized fish; non-stressed sturgeon can be subsequently measured and tagged.	Yes. Less selective than gill nets, may be better suited for demographic assessment; non-stressed sturgeon can be subsequently measured and tagged.	Yes. May be effective for juveniles, which use deeper channel and pool habitats; non-stressed sturgeon can be subsequently measured and tagged.	No. Gear probably unsuitable for capture of Pallid Sturgeon.	Yes. May be effective for adult fish, which are piscivorous and use specific habitats or are attracted to bait; non-stressed sturgeon can be subsequently measured and tagged.	Yes. May be effective for very young juveniles, which are entrained in flow or leaders.

LIFE HISTORY TYPES AND UNDERLYING TRENDS

A critical assumption in trend detection is that the portion of the population that is monitored is in fact relevant to species abundance targets. Here, we can perhaps think of Missouri River Pallid Sturgeon as an artificial "super-population:" composed of

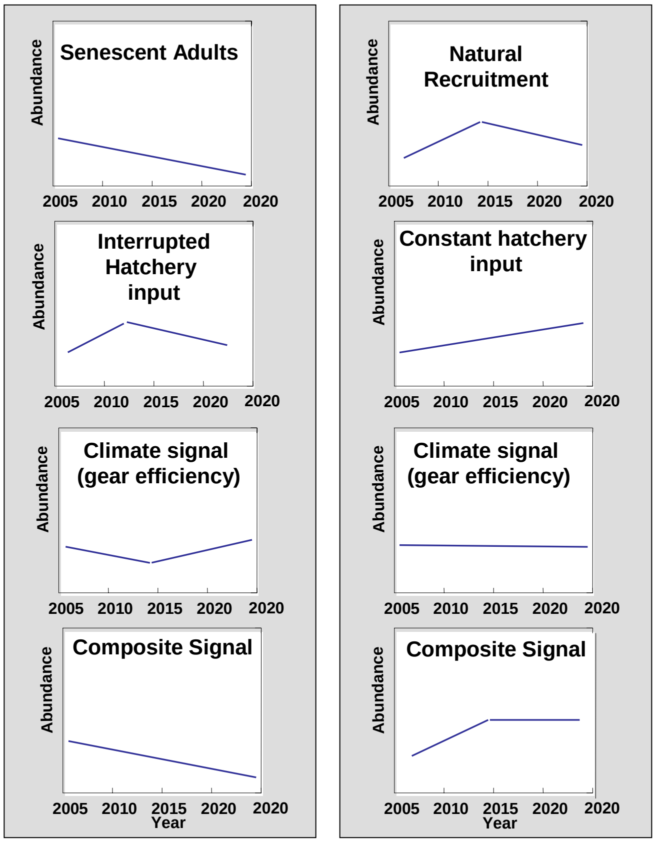
1) Two distinct populations above (segments 1-4) and below the Fort Peck Dam (segments 5-14)
2) Relict large and old Pallid Sturgeon, endemic to Missouri River numbering in the scores to hundreds
3) Hatchery-released annual cohorts numbering in the thousands
4) Hybrid Pallid x Shovelnose Sturgeon, which seem to be increasing in frequency in the lower Missouri River

Each one of these super-population groups entails certain assumptions regarding recovery goals for Missouri River Pallid Sturgeon. A trend analysis that combines all these types and other sources of interannual variation may represent any number of underlying processes. Two of any number of possible scenarios are presented in Figure 5. In the first scenario, (1) no natural recruitment occurs, and continued declines over decades occur due to natural attrition of adults; (2) Hatchery input continues for a decade, then halts and hatchery cohorts decline thereafter due to natural attrition; and (3) climate causes a decadal cycle of wet dry years causing gear efficiency to first decrease then increase. Under this scenario, a declining trend is observed, yet without understanding the component trends interpretation is ambiguous. In the second scenario, (1) Natural recruitment occurs over a ten year period, then is interrupted; (2) Hatchery input continues over the 15 year period; and (3) Interannual variations in climate and gear efficiency is negligible. Under this scenario, the overall trend first increases and then is static, yet underlying trends substantially vary from this trend.

Discerning underlying trends depend upon increased information on component life history types and underlying ecosystem changes. Further, the groups may interact in important and not necessarily beneficial ways. Predicting trends for each group independently will entail much less confidence than the power analysis indicated for the combined groups. Thus, understanding factors that contribute to overall trends will require increased sampling intensity, ancillary information including tracking abundance (occurrence) data separately for wild and hatchery Pallid Sturgeon, careful identification of hybrid Pallid Sturgeon, and more information on how environmental change affects gear efficiency and vital rates.

Additionally, hatchery released cohorts provide an opportunity to deploy released fish in ways that are strategic in estimating abundance trends and population attributes. For instance, releasing larger Pallid Sturgeon could permit mark-recapture estimates of both hatchery and wild sturgeons. Releasing multiple cohorts could permit estimation of survival rate. Similarly, targeted releases of hatchery fish among habitat types, segments, and years could permit spatio-temporal variance in vital rates to be estimated, rates that could be representative of wild Pallid Sturgeon.

Figure 5. Underlying trends in fates of wild pallid sturgeon (top panels), hatchery cohorts (second panels), climate or gear efficiency (third panels), and the overall composite signal (bottom panels).



RECOMMENDATIONS

1) Detection of 1% to 5% per year changes in abundance for a 10 year period is appropriate to the life history and recovery of Pallid Sturgeon, and ecosystem management of the Missouri River. Power gains that could result in a program designed to detect trends over longer periods (e.g. 20 years) are probably offset by the risk of extirpation.

2) The current Pallid Sturgeon monitoring program is not sufficiently powerful to detect future population/occurrence changes of less than a few percent per year. Still, with

moderate increases in sampling effort, particularly increasing the number of bends per segment, power greater than 75% is achievable. There is potential loss of power with the current strategy of random site selection with segments. In consultation with expert statistical advice, consideration should be given to combining segments if relevant hydrographic provinces exist at scales larger than segment but smaller than Missouri River ecosystem levels.

3) The Sturgeon Season should be formalized with goals and deployments specific for indexing abundance levels for Pallid Sturgeon. Random site selection within segments and the Missouri River should be preserved and expanded, and increased sampling effort should be made with those gears expected to be most effective: gill and trammel nets. Deployments of other gear types should be eliminated unless targeting specific biological assessment goals.

4) The Community Season should take full advantage of opportunities to sample juvenile, hatchery, and hybrid Pallid Sturgeon and deployment of gear types that target specific biological and experimental gear studies. If possible, random deployments of gill and trammel nets (albeit with shorter soaks and temperature proscriptions) should be retained to provide increased power in indexing sturgeon abundance trends.

5) Evaluate relative contribution of life history types within the Missouri River Pallid Sturgeon "super-population" (i.e., the admixture of Missouri River sub-populations, old wild pallids, hatchery cohorts, and hybrid sturgeons).

6) Shovelnose Sturgeon may be important in terms of the hybridization issues or as an indicator species of habitat change, but despite confamilial taxonomy and ecological sympatry for important life history stages, there is no evidence that they represent surrogate species for Pallid Sturgeon.

7) The power analysis should be repeated regularly (perhaps 3 year time intervals) to check the efficiency of the monitoring program.

CHAPTER 8: ADAPTIVE MONITORING

INTRODUCTION

Charge to the Review Panel: To provide input on adaptive monitoring to maintain this program as a "living program"

All management and restoration projects directed at species and complex ecosystems have multiple sources of uncertainty. This program is no exception. There are several sources of uncertainty surrounding the Pallid Sturgeon, other fish species and the Missouri River ecosystem. Adaptive management is designed to allow resource managers to act in the face of acknowledged uncertainty, designing monitoring and management actions to reduce uncertainty over time while permitting change in response to surprising outcomes. There are many definitions and types of adaptive management (Holling, 1973, 1978; Lee & Lawrence, 1986; Bormann, et al., 1993; Halbert, 1993; McLain & Lee, 1996; Salasky, et al., 2002. See also the Conceptual Models section of this report). At their core, they all share the goal of combining ecological research and management actions by integrating program design, ecological management practices, and ecological monitoring and using these to test assumptions methodically (Ringold, et al., 1996, 1999). In this way, managers gain an understanding of how to adapt their management approach while concurrently answering questions about whether their approach is effective, and why it may or may not work (Salasky, et al., 2002, Smit, 2003).

RELATIONSHIP BETWEEN ADAPTIVE MONITORING AND ADAPTIVE MANAGEMENT.

Adaptive management cannot be implemented without some mechanism for comparing the outcome of decisions to selected performance goals and measures. Typically this means systematic data collection through a monitoring program designed and implemented in order to provide baseline for comparison (See Table 10). For instance, the Comprehensive Everglades Restoration Plan (CERP) relies on a series of performance measures and monitoring programs known as the Monitoring and Assessment Plan to evaluate the performance of CERP and provide a framework for modification if needed. (Comprehensive Everglades Restoration Plan http://www.evergladesplan.org; National Academy of Sciences and Engineering 2003).

Adaptive monitoring also allows scientists and managers to proceed in the face of uncertainty. It treats monitoring as an element of the learning process rather than as an independent step that follows learning. See for example, Mulder, et al., 1995; Ringold, et al., 1996, 1999; Possingham, 2002 and Smit, 2003. Under an adaptive monitoring scenario, decisions are "provisional" and contingent on information and results. Adaptive monitoring increases the ability of scientists and managers to respond to new information. Adaptive monitoring feeds back into monitoring activities and adaptive management. The Northwest Forest Plan, adopted in 1994, includes a large monitoring component which addresses trends in several endangered species and in their forest habitats (http://www.reo.gov/monitoring/, Mulder, et al., 1995). This monitoring program is built on an adaptive framework. When these monitoring programs were initially designed, it was recognized that available information was limited in scope, and that there were significant uncertainties about the adequacy of the monitoring program to address management issues. Planners made the strategic decision to initially include several alternatives (built-in redundancy), with the expectation that (after an initial period of data collection and evaluation) some alternatives would be dropped. Specifically, it has always been the hope that cheap, efficient monitoring of forest habitat (from imagery) could replace expensive, technically difficult monitoring of Spotted Owls. Periodic review of all aspects of monitoring strategy is explicit in the design documents, and decisions are regularly made that change monitoring in the light of new information, budgetary constraints, etc. (S.P. Courtney, B. Mulder *personal communication*, 2004)

Table 10. Overview of generalized monitoring program with an adaptive monitoring component.

Overview of a Monitoring Program

1. Clear statement of objectives
   – What do we want to know?
2. Clear understanding of resources available
   – What can we do, and afford?
3. Initial information about system
   – What can we measure?
4. Initial design suggestions
5. Initial analysis
6. Develop monitoring program
   – Design of surveys
   – Design of analyses
   – Research on any information still needed

ADAPTIVE MONITORING Reiterate 3 to 6 as circumstances change, and results of previous management "experiments" permit managers to modify or drop some elements, and add others and refine objectives if management priorities or information needs change.

ADAPTIVE MONITORING

There are several key differences between a more traditional approach to monitoring and an adaptive one. Fundamentally an adaptive approach is an iterative process that anticipates new information (Boyle, 1998; Ringold, et al., 1999; Smit, 2003). Traditional monitoring has often been viewed as an isolated activity whereas under an adaptive framework, monitoring, management, and governance are interdependent. Traditional monitoring focuses primarily on the results, whereas in adaptive monitoring the emphasis is on learning and thus program design, indicators, processes, and results are all equally important. Traditional monitoring has often been used as an early warning indicator ("canary in the coal mine"), while an adaptive approach expands this role and makes monitoring a primary tool for understanding the species and system, assessing the effectiveness of monitoring and management, and measuring progress towards goals (Boyle, 1998). Well-designed adaptive monitoring programs also facilitate event-triggered data collection to increase understanding of rare, unanticipated, or episodic drivers of the system.

Adaptive monitoring is a disciplined process where actions or changes to the monitoring program are based on a formal methodology, analysis and assessment. Some proponents would like to see an adaptive monitoring system visualized in terms of an explicit decision tree for those changes that can be anticipated ahead of time. These might include hypotheses regarding what factors limit Pallid Sturgeon recruitment. However, there will undoubtedly be unexpected findings that suggest a different emphasis in monitoring. Any such changes should be checked with the design statisticians to ensure that the survey design will not be compromised. Experimentally testing new methods or gears that fall outside the design framework and in an *ad hoc* manner, while potentially informative, is not adaptive monitoring: Testing new gear falls under research designed to support the monitoring program.

ADAPTIVE MONITORING APPROACH IN THE PALLID STURGEON MONITORING AND ASSESSMENT PROGRAM.

The Pallid Sturgeon monitoring and assessment program is designed to provide important information for the management of endangered species and the Missouri River ecosystem (Fleming, 2004). State and Federal programs have made great strides in cooperation during the 2003 Pallid Sturgeon monitoring and assessment program and should be congratulated for their work, and for providing critical data for power analysis and review of the monitoring program, in the spirit of evaluating and adapting where needed.

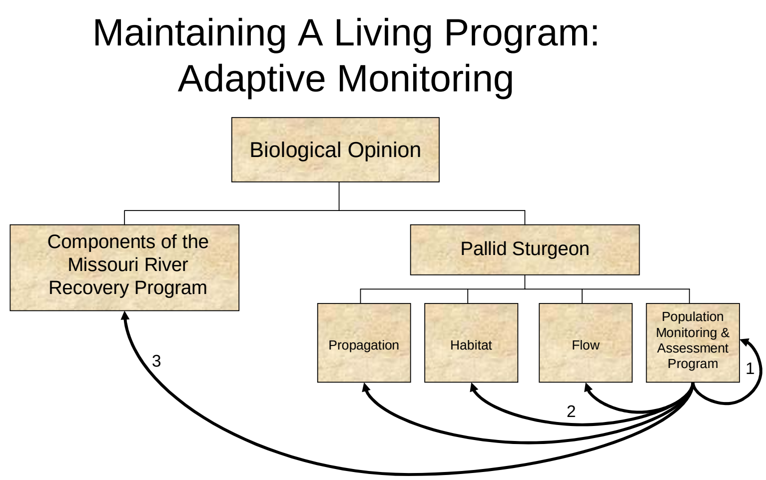
We believe that an adaptive monitoring approach is valuable in this program because uncertainty is high surrounding the species and the ecosystem. An adaptive approach will allow the team to gather essential information in a systematic way, evaluate that information in order to make any necessary changes and to use resources effectively. It will in short, maintain this program as a "living program." However, care must be taken to ensure that an adaptive approach does not entail frequent and dramatic program changes that result in the avoidable loss of usable data and results. Thus, from the very beginning it is important to have good programmatic and statistical advice in the design and implementation of the program that is responsive to the needs of scientists, managers, and policy makers. Review of the Pallid Sturgeon monitoring program at this stage may indeed lead to changes that will result to some data loss. This is normal at this point in any ecosystem-scale initiative, and is better addressed now rather than later.

The Pallid Sturgeon monitoring effort can provide important feedback into two main areas (See Figure 6):

1) The adaptive monitoring program feeds back on itself in order to assess the methodology and information gathered. Results are evaluated against the four stated objectives of the Pallid Sturgeon monitoring and assessment program. An outcome of the evaluation may be a change in monitoring priorities and intensity.

2) Monitoring informs management actions through an adaptive management process. The results of this monitoring effort can and should feed into all the components of the larger Pallid Sturgeon program (i.e. the monitoring and assessment program in addition to the propagation, habitat and flow programs -- See figure 6) to inform decisions regarding science and management. It is equally desirable to have the results feed directly into the adaptive management component of the Missouri River Recovery program. (We note that this effort is currently under development and not yet fully designed or implemented.) Feedback from these other programs and management can in turn help the monitoring program adapt to new information and priorities.

Figure 6.



Role for adaptive monitoring: 1. Monitoring informs design, priorities, and analyses of the pallid sturgeon monitoring assessment program through a feedback loop. 2. Monitoring informs other facets of the pallid sturgeon program and 3. the components of the Missouri River recovery program.

ADAPTIVE MONITORING DESIGN COMPRISES SEVERAL ESSENTIAL COMPONENTS

As the group formalizes an adaptive monitoring approach, several essential components should be specifically included and documented. These components are essential to all adaptive monitoring programs and include:

- Explicitly defined objectives
- Explicit models of the species or system being monitored and managed
- Appropriate design and methodology
- Formal reporting and evaluation of results
- A mechanism for incorporating results into future monitoring and management actions

Explicitly defined objectives. Clear objectives are an essential foundation for adaptive monitoring. Without explicit objectives and measure of success, scientists and managers cannot know whether their actions are effective or require modification. Where competing objectives have different priorities this should be explicitly stated. This has been discussed in an earlier section of this report (See the Conceptual Model and Monitoring Approach sections of this report).

Explicit models of the species or system being monitored and managed. Like the objectives, a baseline understanding of and assumption of the species or ecosystem must be made explicit to provide a foundation for learning. This model changes as new information is gathered. When there is little information available, the initial model may be qualitative and general. See section on Conceptual Models in this report.

Appropriate design and methodology to gather and analyze information. The design and methodology must be tied to specific objectives and indicators. The design must have sufficient power to be able to meet the stated objectives of detection, and must be feasible logistically and economically. More information on design and methodology is provided in the Monitoring Approach and Survey Design sections of this report.

Formal reporting and evaluation of results on a regular basis. Adaptive monitoring cannot be implemented without some mechanism for reporting and evaluating the outcome. Results need to be evaluated with respect to the goals and objectives of the monitoring program. Power analysis provides a quantitative measure of the ability of a monitoring program to meet specified detection goals.

<u>Reporting</u>

In this first effort, there is unevenness in reporting, which State and Federal participants recognize and are making efforts to reduce. Annual report format, data tabulation on pallid and indicator species numbers and CPUE by gear, site/region, and month and related graphic displays would seem easily standardized. Historical data should also be presented in each annual report as trends begin to become apparent. In addition, it may be useful for participants to review database fields together to ensure that these are compatible across all monitoring teams.

Evaluation of Results

An evaluation of results against performance goals and objectives may indicate that changes in monitoring priorities and activities are warranted. For instance monitoring for a threatened species may need to be intensified when the population is declining. Population declines result in fewer individuals being sampled per unit effort which leads in turn to lower power of detection. Thus statistical concerns in addition to management ones over the potential loss of a species dictate that an increase in monitoring effort is needed. Conversely, if the population increases, it can lead to higher catch per unit effort and higher power of detection. Under this scenario, monitoring effort may be decreased or in some cases stopped and resources diverted to other critical needs. In some cases, it may be satisfactory to gather descriptive data for background knowledge or change-detection purposes, even if sample sizes are inadequate to test scientific hypotheses, but this decision should be made explicitly and the accompanying range of management or other implications accepted.

A challenge for any adaptive monitoring program is to design the methodology so that it can be modified without losing the ability to use data collected to the point of modification. Changes in sampling design and data collection frequently result in data loss when results from different methodologies cannot be combined into a comprehensive analysis. When a large scale adaptive monitoring program is undertaken in a system with high uncertainty, it is prudent to consider an initial time period as preliminary or pilot program. This initial period may last one or two years depending on the species and ecosystem. During this time the learning curve will be steep and it is likely that as information is evaluated, certain methodologies will prove ineffective and new elements will need to be incorporated. It may not be possible to roll over data gathered during this initial period into the next phase. To minimize data loss it is important to work towards a stable core design and not to spend too long in a pilot phase. Otherwise this defeats the purpose of a monitoring program. From the outset, an adaptive monitoring program needs to consider working towards a stable core program while maintaining flexibility for change as the program evolves. This is a complex task and thus statisticians with expertise in the design of large surveys should be involved from the beginning, particularly since real-world monitoring protocols covering large areas are always complex, somewhat arbitrarily stratified, unbalanced, partially nested, and in general not completely amenable to off-the-shelf statistical tests – none of which, in itself, precludes robust analysis. The Pallid Sturgeon monitoring and assessment program has been in an initial development and implementation stage and is approaching the end of the pilot phase. This is the time to combine technical advice with the needs of the management program in order to move smoothly into a long-term stable phase of the program.

A mechanism for incorporating results into future actions.

Incorporating results into future action requires a method for making decisions and decision makers empowered to take action. Ideally some type of decision tree that has triggers for action should be incorporated into a formal evaluation process. We recommend that the assessment team consider using a decision tree to help them evaluate and make decisions on where to prioritize and continue effort.

Equally there must be some form of institutional mechanism for feeding information gained back into future monitoring and research actions. Without this mechanism, learning will not improve future monitoring or management performance. To be effective any institutional mechanism, whether it is a committee or other structure, must be empowered to make decisions. In this situation, the Pallid Sturgeon Monitoring and Assessment Team is the primary institutional mechanism. To date the team has maintained a strong program characterized by cohesiveness and fruitful interactions among group members. These interactions should be expanded to include a formal adaptive monitoring evaluation.

To the credit of the Pallid Sturgeon Monitoring and Assessment Team, this review is in effect a form of adaptive monitoring. The methodology has been evaluated with the help of an external advisory group in order to review and strengthen the program to ensure that it meets its objectives. The review has brought together the science and management components in order to ensure that monitoring efforts address the management goals. We applaud the team for recognizing that review is an important component of the program, and for its willingness to carry out this review. We recommend that the team develop a formal process for integrating their results into the monitoring program, and eventually into the other components of the Pallid Sturgeon program and the overall Missouri River recovery program. We suggest that the team review its results annually, and that periodically, perhaps every three years, the team conducts a formal review of its efforts and results in an adaptive monitoring framework. These types of reviews are built into other large ecosystem programs such as the Northwest Forest Plan, the Sierra Nevada framework, and CALFED. As part of this periodic (e.g. 3 year) effort, a more detailed statistical analysis is warranted to evaluate progress towards program goals and modify procedures according to the adaptive monitoring framework. Analyses should include at a minimum (1) revised power analysis and trend analysis for Pallid Sturgeon and any indicator species, (2) gear comparisons and selectivity assessment, (3) statistical habitat models, (4) exploration of other quantitative and qualitative models appropriate to the goals and hypotheses of the recovery program. As indicated elsewhere in this document, additional mark-recapture and telemetry studies could complement the gill net/trammel net assessment of Pallid Sturgeon, and could enable alternative population trend analyses that use demographic calculations, probably through spatially-explicit individual-based modeling. Careful planning of tagging studies together with gear deployments should permit quantitative assessment of gear efficiency (e.g., size selectivity of different gill net mesh panels). This is particularly true for Shovelnose Sturgeon and such derived efficiency coefficients ought to be similar across similar sized Pallid Sturgeon. These studies and statistical reviews should be carried out in reference to goals objectives and any changes in priorities.

ANALYTICAL OPTIONS

There is no single correct approach to a statistical framework for testing habitat-fish associations for long-lived organisms distributed across, and moving between, multiple habitat types. With accumulation of data over the future duration of the monitoring program, geostatistical approaches and representations would be appropriate, but this may take several to many years. In the shorter term, the hierarchical nature of habitat sampling would seem well suited to classification and regression tree (CART) models and these should be explored as procedures that predict nested habitat associations of sturgeon and indicator species (Magnuson, et al., 1998; Norcross, et al., 1999). Another potentially fruitful approach are generalized additive models (Stoner, et al., 2001). Finally, there remains much work to be done in linking an overall conceptual model for large impounded river ecosystems and expected trophic and species interactions, and environmental forcing (see the Conceptual Model section). These are highly relevant to Pallid Sturgeon recovery and periodic outside exploration of ecosystem models using Missouri River monitoring data should be encouraged. As noted in earlier sections, different choices of analytical frameworks may impact the choice of the most effective monitoring protocols.

BENEFITS OF DEVELOPING A FORMAL ADAPTIVE MANAGEMENT FRAMEWORK

Adaptive monitoring can be time consuming but the benefits can be significant for the resource and for the program. Results indicate that when a group goes through assessment and evaluation in an adaptive monitoring program they not only gain valuable information on the adequacy of their design and indicators but the process results in greater commitment to the program, provides participants with a solid argument for advocating for specific actions and for support for the program (Boyle, 1998).

There is a role for an external advisory or review group. A well-constructed external technical advisory group can provide critical expertise and knowledge that is missing from the assessment group. By design this external group will not have complete knowledge of the context or other details of the program. In carrying out a review it is important to recognize that there is usually no single solution; rather there are options with associated uncertainties and risks. An external advisory group that is facilitated effectively can be enormously helpful and successful in assisting a group like the Population Assessment Team arrive at their own best solution (e.g. Boyle, 1998). There is also no fixed prescription for designing an effective technical advisory and review apparatus. The need of the group seeking input is a major determinant of the type of structure that will work best. However, it is important that an external advisory group (whether blue ribbon panel, standing working group, or specialist consultants) be viewed as highly qualified and independent.

RECOMMENDATIONS

1) We recommend that the team use an adaptive monitoring approach that informs the monitoring and assessment program as well as other components of the Pallid Sturgeon program and Missouri Recovery effort. A program of periodic analysis, perhaps every three years, is important to the goal of adaptive monitoring, and in making monitoring program data more relevant to Missouri River recovery program goals and outcomes. Thus monitoring and assessment results should be reviewed in reference to the stated management objectives and priorities.

2) Annual reporting is a critical component to the success of the monitoring program. Continued effort by state and federal monitoring teams to standardize annual reporting of monitoring products and compiling a central database should ultimately ease their reporting burdens and make data products more useful to the assessment team, other scientists, managers, and the public.

3) Consider the effort to date as the key first step in design and evaluation of the program and if appropriate modify the design now in light of stated objectives and acceptable levels of detection, using a statistical/technical advisory group.

4) Currently there is no infrastructure to support periodic assessment of monitoring data. One model would be to employ a team of expert environmental statisticians and modelers, and engage them to conduct power and trend analyses, develop habitat statistical models, and on occasion explore innovative ecosystem-based modeling frameworks, appropriate to recovery program goals.

5) Create a mechanism for feeding the results into the overall Pallid Sturgeon program and the larger Missouri River recovery effort (when it is developed). As part of that effort consider periodic external technical advice and review.

CHAPTER 9: OVERALL RECOMMENDATIONS

OVERALL RECOMMENDATIONS

The panel was charged with reviewing the strategy, overall design, consistency, appropriateness, and power to statistically detect population changes for the Pallid Sturgeon monitoring program defined by the 2000 and 2004 Biological Opinion documents, the 2003 Biological Assessment, the 2004 and the draft document on "Long-Term Pallid Sturgeon And Associated Fish Community Assessment For The Missouri River And Standardized Guidelines For Sampling And Data Collection", augmented by a variety of ancillary documents, workshop presentations, and interviews. The panel generally concluded that the Pallid Sturgeon monitoring program, as designed and executed though two initial years, is well-conceived, follows standard practices of the fish population monitoring community, and constitutes a credible start on a long term monitoring program.

As with any ecosystem-scale population study involving multiple institutions, habitat types, and species, the project design involves trade-offs among objectives, methods, and detailed approaches, and is therefore complex and perhaps not as integrated as it could be. Choices among methods can rarely be made from first principles, and therefore it is an empirical matter, on which evidence continues to accumulate, on what methods and analyses are most effective in practice. The panel commends the Assessment Team for undertaking a timely review, and offers the following recommendations as steps toward further clarifying approaches and integrating fish monitoring efforts throughout the Missouri River system. More details on each recommendation are given in the preceding sections.

"BIG PICTURE" RECOMMENDATIONS:

1) *Conceptual modeling*. We recommend that the Assessment Team and associated programs institute a formal conceptual modeling process, analogous to that that has been undertaken in other large ecosystem restoration initiatives. Goals include to formalize hypotheses about environmental and management controls on Pallid Sturgeon populations, to identify the functional relationships between monitoring measurements, indicators, performance measures, and triggers for management, and in general to develop feedback to and from managers on goals- specific hypotheses to be tested. Although it is beyond the scope of this review, conceptual modeling is also generally thought to be an essential step in the development of effective adaptive management plans.

2) *Designating core monitoring activities.* The current planning documents do not make it as clear as they might which activities, sites, gear deployments, and assessments are essential to inform the highest priority goals of the Biological Opinion, and which are undertaken for research, methods development and testing, ancillary or localized science needs, or other secondary purposes. Separating core activities, to be implemented throughout the entire Missouri River System, and "other" activities that might be as effectively done locally or on a research or pilot basis, might help focus resources on the most important applications and assessments.

3) *Developing a working group on Pallid Sturgeon population status, monitoring needs and research.* The panel believes that the technical challenges of the monitoring program and the need to coordinate the objectives and field activities of multiple monitoring organizations require oversight from a technical working group that meets regularly and has established mechanisms for continuous consultation. There are multiple models for how such a group could be organized.

4) *Using adaptive monitoring.* The monitoring design should contain procedures, including perhaps pre-established decision trees and triggers for action, allowing it to be modified to take advantage of new information without a loss of previous data. The present program may be treated as a pilot for the full adaptive monitoring design

5) *Regularly reviewing the program, both internally and externally.* The panel recommends that the program establish processes for independent review of the monitoring design, data, and analytical framework on an ongoing basis. Mechanisms could include an external technical advisory group, regular peer-review of program documents, workshops, and engagement of expert consultants with experience in comparable ecosystem-scale monitoring efforts. In particular, the panel suggests that the team institute a periodic power analysis, perhaps every 3 years, to assess whether the monitoring design and levels of effort and resources are sufficient to statistically address the information needed to implement the Biological Opinion and manage the environment of the Pallid Sturgeon population.

6) *Mechanism to feed results into management and monitoring.* It is important that findings of the monitoring program be processed and communicated in ways and on a schedule useful to both monitoring programs for adaptive monitoring and to system managers for adaptive management. Assessment of communications and decision support systems should be a critical part of the design of the adaptive management program.

RECOMMENDATIONS ON STATISTICAL ISSUES:

1) *Form a statistical/technical advisory group* - including expertise on statistical design, trend analysis and power analysis, and remote sensing and telemetry data. The panel suggests that this step be taken immediately, and that the advisory group be actively engaged in the current review of the monitoring program and in the design of future

adaptive monitoring and adaptive management procedures. There are multiple models of how such a group could be implemented. The monitoring team may choose to have more than one advisory apparatus, such as a small group that meets regularly, combined with a "blue ribbon" panel constituted occasionally for overall program evaluation and peer-review. The panel suggests that the advisory group be constituted to provide ongoing statistical advice, combined with advisors with expertise in genetic analysis and technologies, remote sensing and GIS, process modeling, and individual-based and/or demographic modeling.

2) *Dedicated statistician on staff or 'on retainer'.* The statistical complexity of the monitoring design, combined with the challenges of conducting trend analyses on rare, long-lived species in a spatially complex environment suggest that the program could benefit from more in-house or on-call statistical expertise. The ideal candidate(s) would combine specialized knowledge of time-series analysis, power analysis, geospatial analysis, and statistical design.

3) *Regularly re-evaluate and adapt monitoring program in light of new information.* The statistical adequacy of the sampling efforts, opportunities to prune activities resulting in low information content or add new methods or sites promising high returns, and the decision steps of adaptive monitoring all require regular re-evaluation by the monitoring team and its advisory apparatus.

TECHNICAL RECOMMENDATIONS:

1) *Clarify geographic and management units.* The core of the current monitoring design is habitat samples stratified by major river segments, but there are some additional complexities reflecting jurisdictional boundaries and sites of special management concern or those used in more specialized studies. The panel concurs with the monitoring team that there are probably opportunities to simplify the monitoring design and gain statistical power by concentrating on a single river segmentation which reflects major subregional habitat changes, such as those caused by a dam, major confluence, or regional differences in levees, floodplain connection, and geomorphology.

2) *Separate habitat and population monitoring.* The current documents and statistical design somewhat confound Pallid Sturgeon population trend assessment and assessments of habitat change and suitability. They can probably be profitably separated, at least at the level of conceptual models, objectives, and criteria for data analysis and decisions.

3) *Utilize two sampling seasons.* The panel suggests that the current practice of using different methods under winter and low temperature conditions (the "Sturgeon Season") than in summer/high temperatures (the "Community Season") be codified and perhaps further differentiated. Concentrating efforts on the most efficient gear types in the "Sturgeon Season" can give more powerful population trend assessments. More diverse gear and locations in the "community season" can serve to both assess other species and to detect conditions and locations promoting reproduction and juvenile success.

4) *Gear, season, effort, and their effects on statistical power.* There has been some proliferation of gear types and changing seasonal effort levels without clear articulation of their relationship to the power of the core trend analyses and the specific information needed for setting policy. The panel recommends that the monitoring team explore opportunities to simplify and standardize the gear and effort levels for the core activities to be deployed throughout the Missouri River System. The panel still encourages exploratory use of additional gear and methods for research, local information needs, or to test for future applicability, but suggests ongoing technical review of the scopes of such efforts.

5) *Trend analysis: small changes over long periods.* Population trend analyses of long-lived rare species are intrinsically long-term and limited in their sensitivity. Managers and the monitoring community need to assess the degree to which achievable statistical certainty meets management needs and expectations.

If the ability to detect change under the current design and level of effort is found to be insufficient for policy purposes, statistical power can be increased somewhat by increasing sampling effort. Increasing the number of bends sampled contributes more to power than subsampling within bends, at the expense of greater logistical complexity and costs.

6) *Evaluate different life-history stages.* Larvae, juveniles, and adults are likely to be found in different locations by somewhat different methods. The implications of the information for population status and projection also vary. Determining the best methods and optimal resource allocation toward detecting different stages is a challenging technical problem, and should be addressed statistically as part of ongoing adaptive monitoring.

7) *Use caution in treating Shovelnose Sturgeon as a surrogate for Pallid Sturgeon in trend analysis.* Shovelnose Sturgeon and other candidate "surrogate species" may respond differently to changing habitat quality than Pallid Sturgeon, and may interact in complex ways with Pallid Sturgeon. The panel believes that using shovelnose captures to assess methods and risks from competition and hybridization is valuable, but is skeptical that population changes in any "surrogate" species is a reliable indicator of status and trends in Pallid Sturgeon populations.

8) *Consider event-based triggering of more intensive sampling.* The panel suggests that the monitoring team evaluate new literature suggesting event-based intensive sampling as a part of trend assessment for applicability in the monitoring program.

9) *Evaluate demographic models, including individual-based models, as alternatives to the current design.* Many rare-species recovery studies have found it more effective to estimate lifetime reproductive outputs (estimating λ or R_0) than to conduct time-series analysis on population size as a measure of recovery or the effectiveness of species protection. Choosing to add analyses of this kind may suggest an increased emphasis on

monitoring individual fish as an alternative to the present habitat-centric monitoring strategy.

10) *Incorporate new genetic research technologies into the monitoring program as the become cost-effective.* Methods for assessing genotypes are improving rapidly in both effectiveness and cost. The team, with outside advisors as needed, should evaluate whether new methods can and should be deployed now to address characterization boundaries, movement, hybridization, and identification of individuals. Even if new methods are not yet cost-effectively deployable, the program should be prepared to take advantage of future developments. Approaches include:

a) *Developing a protocol for feedback from genetic tests to analysis and shared fish-occurrence databases.*
b) *Saving vouchers for future genetic testing.*
c) *Specifying how hybrids will be defined, detected, and treated*
d) *Establishing a process, perhaps through the technical advisory apparatus, for assessing new technologies, such as gene chips, advances in sequencing, and microsatellite technologies.*

RESEARCH RECOMMENDATIONS:

The monitoring team and planning documents identified a number of research needs that will support scientific understanding of Pallid Sturgeon and the Missouri River System and that my contribute to future monitoring, but that are not ready to be deployed region wide today. The panel recommends ongoing investment in this kind of research. These include:

1) *Telemetry.* If adult wild Pallid Sturgeon can be fitted with telemetry devices without increased mortality, the information gained could contribute to assessing:

a) Habitat use
b) Demographic parameters, and
c) Interactions with Shovelnose Sturgeon in the spawning season,

all of which are essential to constructing predictive demographic or individually-based models.

2) *Hybrid viability*-- The derivation (sex of parents), survivorship, and reproductive capabilities of hybrids appears to be poorly known, and is crucial to assessing genetic risks to Pallid Sturgeon.

3) *Spawning and early life stage of Pallid Sturgeon.* Habitat restoration and floodplain connectivity efforts could be made more effective by a better understanding of the requirements and cues for spawning and early survivorship.

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