Independent Science Advisory Panel Technical Memo

Pallid Sturgeon Monitoring Program "Discuss and Feedback" – A Report from the Independent Science Advisory Panel

17 January 2023

In recognition and continuation of the technical advisory role and review capability of the Independent Science Advisory Panel (ISAP) to the Missouri River Recovery Program (MRRP--obligated under the Final Biological Opinion on *Operation of the Missouri River Mainstem Reservoir System* and other environmental commitments and projects), the panel was engaged in a "discuss and feedback" session on 14 November 2022, addressing the state of Pallid Sturgeon monitoring and assessment with the Army Corps of Engineers' staff and consultants. An informative discussion built upon the ISAP's review of the Pallid Sturgeon Population Assessment Program (PSPAP), subsequent technical discussions on Pallid Sturgeon monitoring, and Fall Science Meeting Webinars in October 2022.

This deliverable to the MRRP offers observations and recommendations from the meeting, emphasizing key points that should be considered by the Corps as it continues development of a Pallid Sturgeon monitoring program. The panel recognizes substantial strides by the Corps in operationalizing the *Science and Adaptive Management Plan* (dated August 2018), while noting that significant elements toward an implementable sampling design remain unresolved and outstanding. The ISAP acknowledges the commitment of the Corps to developing an effective, efficient, and accountable monitoring program targeting Pallid Sturgeon in responding to this charge to the panel.

Purpose, Context, Desired Outcome: *This engagement will build upon results of the ISAP's 2020 review of the Pallid Sturgeon Population Assessment Program (PSPAP) and subsequent technical discussions with the ISAP. Participating ISAP members will receive an update via a webinar on the status of all Pallid Sturgeon monitoring efforts (not limited to PSPAP). The "Update Webinar" will be held in October prior to the 2022 Fish Fall Science Meetings (FSMs) on November 1 and 2. Some of the FSM presentations will provide more detail on key components for the ISAP's review under this assignment. On November 14, the ISAP and Fish Technical Team will meet in person to jointly discuss challenges regarding pallid sturgeon monitoring and identify effective ways to address them. The desired outcome is sharing of progress in monitoring design and implementation, and identification of possible refinements to better serve the needs of the Missouri River Recovery Program. Technical discussions between ISAP members, the Fish Technical Team, and agency staff are expected to result in increased mutual understanding of the current monitoring program status, challenges, and potential avenues for improvements.*

Overview

The Pallid Sturgeon Discuss and Feedback engagement in November 2022 provided a productive forum for Fish Technical Team members and the ISAP to discuss important aspects of the Pallid Sturgeon Population Assessment Program (PSPAP). The discussion focused on several essential elements related primarily to age-0 fish monitoring that included -- (1) the merits of random versus targeted sampling, (2) the need to increase age-0 fish sampling efforts in the lower Missouri River (LMR), (3) potential metrics for measuring age-0 fish abundance (including CPUE, abundance, presence/absence), and (4) the distinction between monitoring in support of direct, empirical assessment of management actions and monitoring used to support the Pallid Sturgeon population modeling.

The panel received these charge questions –

I. What additional refinements (e.g., sampling design, response design, data analysis) should be considered for PSPAP population monitoring in general?
II. Given the proposed refinements in (I.), what specific tasks do you recommend for the Fish Technical Team in FY23?
III. How would the refinements under points (I.) and (II.) improve management decisions?
IV. How would you rank the order of importance of your recommendations?

In addressing the questions, the panel observed and registered concerns related to age-0 Pallid Sturgeon monitoring, emphasizing (1) the importance of documenting natural reproduction (age- 0 fish) and recruitment of young sturgeon in the LMR and (2) the critical need to develop a robust monitoring program to facilitate a better understanding of the environmental factors affecting the abundance, recruitment, and distribution of age-0 fish, with direct application to managing Pallid Sturgeon and its habitat.

The technical observations and suggestions presented in this document should be viewed by the Corps and MRRIC, not as prescriptions or analytical directives, but as prompts to stimulate and facilitate continued discussion toward development of a monitoring program in support of the MRRP that can deliver the best available scientific information, as required under the federal Endangered Species Act.

Question 1: What additional refinements (e.g., response design, sampling design, data analysis) should be considered for PSPAP population monitoring in general?

Data that should be collected and how those data can be acquired and synthesized -- protocols for fish sampling and habitat monitoring

The abundance of age-0 Pallid Sturgeon represents a critically important monitoring metric. It confirms that natural reproduction has occurred, and if measured precisely, can be used to evaluate the environmental factors that influence age-0 fish abundance and recruitment. The genetic information obtained from age-0 Pallid Sturgeon can be used to address important questions relating to maternal contribution (the proportion of the annual catch that are siblings) or successful recruitment of older year classes (future collections of wild subadult or adult fish).

Recent successes by fisheries scientists in locating and collecting age-0 sturgeons and characterizing their habitat is an important accomplishment for the age-0 sampling program. Preliminary findings recognize 2021 as a record year for the capture of age-0 Pallid Sturgeon in the lower Missouri River. Ongoing analyses of the river's hydrodynamic and hydraulic characteristics linked to age-0 fish locations provide a strong basis for understanding site-specific habitat features important to young sturgeon. Habitat metrics taken at occupied sites can be used to -- a) validate model predictions for sampling-site selection, b) identify prospective environmental factors (habitat attributes) associated with the distribution and abundance of age-0 fish, and c) provide useful data that can be used to increase design efficacy of engineered IRCs. Successful sampling for young Pallid Sturgeon underscores the need to expand age-0 fish sampling in the lower Missouri River and make it a priority for the MRRP. A major hurdle to expanding the age-0 fish monitoring program lies in development of a robust monitoring program that links abundance or recruitment of age-0 fish to habitat heterogeneity, environmental variation, and future management actions.

Monitoring programs for species of conservation concern seek to answer two critical questions -- 1) What is the current state (status) of the species? and 2) How is the status of the species changing over time (temporal trend) or space (spatial trend)? For such species, the common state variables in monitoring programs are abundance, occurrence, geographic distribution, and, less commonly, demographic parameters, such as survival and birth rates (Noon et al. 2012). Status and trend, two essential demographic attributes, can only be reliably estimated by first meeting specific statistical criteria. Most fundamental is a defensible sampling design. Design issues relevant to estimating the current state of a species focus on -- 1) the number of sample units required for a precise and unbiased estimate of the current state of the population, 2) the size and shape of sample units, 3) how the sample units are arranged in space, and 4) the temporal pattern of sampling across years.

In fish and wildlife investigations supporting conservation planning efforts, abundance is the primary monitoring state variable. There are multiple reasons for that choice, but dominant in both fisheries and wildlife disciplines is a focus on sustainable levels of harvest of commercial and game species. For non-harvested species, such as threatened and endangered species, abundance is the key state variable because of its fundamental relationship to persistence probability and geographic distribution. Abundance ratios from sampling over time are also the fundamental metric for estimating population growth rate ($\lambda = N_{t+1}/N_t$). Importantly, recovery criteria for most species listed under the federal Endangered Species Act are expressed in terms of abundance and distribution.

Approaches for estimating age-0 fish occurrence or abundance include 1) presence/absence data, 2) catch per unit effort (CPUE, the number of fish per trawl), and 3) total number of fish per site. Of these three metrics, CPUE is the most frequently used to assess population status and trends. As a measure of relative fish abundance, CPUE is assumed to be proportional to abundance at a site (that is, the total abundance over space). This a reasonable assumption so long as catchability of fish remains similar across time and space. For trawls, the abundance of age-0 fish can be estimated from depletion sampling (Hilborn and Walters 2001) where the rate of decline in fish abundance (from trawl S_1 to S_n) can be used to estimate initial population size at S_0. Depletion-based sampling comes with challenges; specifically, the considerable time and effort required to sample a site, leading to fewer sites sampled per year, which may compound the problem of many 'zeroes' for age-0 sturgeon collections.

It is important to note that monitoring alone does not provide insights into the environmental drivers of change in the abundance or geographic distribution of a targeted species. To gain insights into causation it requires the concurrent estimation of environmental covariates hypothesized to affect a species' abundance and distribution. Since the drivers of change are also dynamic in space and time, they will need to be estimated in parallel with the species' monitoring program.

A fundamental challenge with the current, age-0 Pallid Sturgeon monitoring program is that there is no clear statement of the sample design, no defensible rationale for the current sampling methods, nor any exploration into what design is best for estimating abundance, assessing recruitment, and informing decision-making in an adaptive management program. This stands in contrast to the proposed Piping Plover monitoring program that is based on a two-phase (or double) sampling design that is grounded in the probability-based sampling desirable in fish and wildlife studies. The current Pallid Sturgeon survey design is a type of multi-stage sampling where sampling at each stage is based on a simple random sample. The stage one sample is a random selection (without replacement) of ~ 25% of bends (n) and the second stage is a simple random sample (without replacement) of m = 24 trawls, randomly distributed within the selected bends. Thus, the sample unit is the individual trawl. The monitoring state variable (y) is age-0 abundance estimated from m=24 trawls within each of the primary sampling units. Within each selected bend, the total y-value is estimated by summing across secondary units. Importantly, this design allows inference to the abundance of age-0 fish in the unsampled bends and can provide a "global" estimate of age-0 population abundance across all bends. The estimators for the population total and its variance are discussed in detail in Thompson (2012, Chapter 13) and Hankin et al. (2019, Chapter 9).

Sampling design -- Where and when measurements can be made and a process by which those locations and times are selected

Understanding trends in and distribution of age-0 Pallid Sturgeon will fill critical knowledge gaps, thereby addressing the fate of naturally produced fish in the lower Missouri River. The lack of wild, age-1 Pallid Sturgeon in the LMR brings into question the fate of age-0 Pallid Sturgeon produced there. At present, we know very little about the extent of downstream migration of age-0 sturgeon in the LMR. Do they perish in the LMR? Do they migrate and reside in the Mississippi River? If so, do they ever return to the LMR as juveniles or adults? These and other pressing questions speak directly to our lack of knowledge about recruitment dynamics of naturally produced Pallid Sturgeon in the LMR, which can only be resolved by robust monitoring and evaluation of factors affecting recruitment from age-0 to age-1.

A major concern regarding the current monitoring plan is that stage two of the multi-stage sampling design discussed above is apparently not always based on a simple random sample of trawls. Sampling at that stage appears to deviate from a simple random sample by -- 1) “targeting” trawl samples to locations within bends where observers on the boat believe they will capture age-0 fish or 2) sampling at adjacent locations where previous trawls have captured age-0 fish. Deviation (1) is not defensible because it is likely to provide estimates that are unrepresentative and can lead to false inference to the state of the population. Deviation (2) seems to be a type of adaptive sampling, but it lacks essential sampling design components that contribute to providing unbiased estimates. Since both deviations are not based on a random or probability-based selection of sample locations, they are subject to unrecognized sources of human bias and not repeatable.

Deviations from a probability-based design are motivated by frustrations over the very many samples that return no fish. Fortunately, there are multiple sample designs -- design-based and model-based -- that can minimize the number of zero-samples at stage two (trawls) but remain grounded in a random sample design and provide unbiased estimates of abundance. Design-based sampling is fundamentally different from model-based sampling (Williams and Brown 2019). In design-based sampling, the y-value in each trawl is considered a fixed quantity. In contrast, in model-based sampling the y-value is considered a random variable. Randomness in design-based sampling arises from the process used to select sample units, whereas in model-based sampling randomness arises from the assumed stochastic nature of the model predictions.

“Targeted” sampling can be viewed as a crude type of model-based sampling. The observers on the boat have a “mental model” of the riverine habitat conditions that are likely to be suitable for age-0 fish. The problem is that these mental models cannot be communicated explicitly to independent observers and likely vary across observers. In addition, targeted sampling is likely to introduce biased estimates, referred to in the statistical literature as “selection bias” (Ellenberg 1994). This source of bias typically arises from non-random sampling of the target population.

Mental models about where to take trawl samples are hypotheses about the habitat(s) selected by age-0 fish. As working hypotheses, they need to be tested, which requires that they be made explicit and numeric; for example, as habitat-niche or species distribution models. The following quote form Lord Kelvin (1824-1907) captures the sentiment --

> “When you can measure what you are speaking about, and express it in numbers, you know something about it: but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science.”

There are published examples of model-based designs that are relevant to Pallid Sturgeon monitoring –two of them worthy of consideration are Guisan et al. (2006) and Wright et al. (2022). Those studies use the predicted probabilities of occurrence from a species distribution model (SDM) to generate sampling (inclusion) probabilities for the sample units. The designs suggested by those authors allow for combined inference because sampling probabilities and sample unit selection are each considered to be random (Williams and Brown, 2019). Once fitted, the SDM can be used, for example, to stratify the sample frame, thereby increase sampling efficiency – and in so doing, minimize "zero" samples.

To adopt this approach, those designing the sampling scheme would need to translate their mental models into an explicit statistical SDM. That would require identifying the environmental-predictor variables that form their mental models. Designers would recognize that age-0 Pallid Sturgeon often occur adjacent to strong shear layers separating main-channel high velocity habitats and slower moving or recirculating flow habitats in the lee of groins or other obstacles. These conditions occur in nature, for example in the lees of emergent bars, but also where specific types of river engineering structures coincide with specific planform (channel curvature) features.

Quantifying habitat features and biotic associations -- particularly age-0 Shovelnose Sturgeon -- related to age-0 Pallid Sturgeon occurrence could provide an objective approach for identifying suitable age-0 sampling locations. Once developed, spatial predictions -- the probability that a sample unit is suitable habitat -- from the SDM can be used to stratify the random sample of units. That approach not only increases sampling efficiency but also increases the likelihood of detecting new sub-populations of Pallid Sturgeon.

An alternative to stratification is unequal probability sampling. In that design, inclusion probabilities for sample units are also based on the predicted probability of occurrence derived from the SDM (see Chiffard et al. 2019, Gwenaelle et al. 2010). That is, the probability that a candidate trawl is included in the sample is proportional to the predicted probability of species occurrences based on the SDM, and not on stratification. In the unequal probability sampling design, units are selected without replacement, with probabilities proportional to predictions from the SDMs. In that design, probabilities of occurrence serve as an auxiliary variable used to estimate the inclusion probabilities for a given sample unit (see Hankin et al. 2019, Chapter 8). With unequal probability sampling there is a greater likelihood of selecting sample units with high probabilities of occurrence of age-0 fish and a low likelihood (though not impossible) of selecting sample units with a low probability of providing suitable habitat.

When animals are clustered -- as appears to be the case for age-0 Pallid Sturgeon -- a preferred sampling strategy is to first stratify the populations according to expected abundances (prior stratification based on preliminary survey data as is done in the proposed Piping Plover monitoring program) and then to sample those strata in proportion to their expected abundance and variation. However, prior information to allow stratification often is unavailable. As a result, conventional sampling designs like simple random sampling or stratified random sampling often do not efficiently sample spatially aggregated populations. Estimates of population parameters (e.g., population totals) are therefore likely to be imprecise. In such situations adaptive cluster sampling (ACS) has been proposed as a sampling design that may be more efficient because it allows the inclusion of additional sampling units in the immediate neighborhood of any unit in which the target species is found (see Thompson and Seber 1996; Smith et al. 2004). A design-based adaptive sample involves modifying the sampling design based on information obtained during the survey, while remaining within a probability sampling framework. The advantages of ACS over stratified sampling are believed to be -- 1) an increase in sampling efficiency resulting in more precise estimates of population parameters and 2) an increase in the number of observations of the target species that would result in more reliable estimates of other population parameters, such as species abundance.

The monitoring program for age-1 and older fish is based on mark-recapture (MR) estimation methods. Closed MR models are used to estimate abundance and open-population models can be used to estimate abundance, survival, recruitment, and population growth rate. Those model-based estimates were not considered at the November meeting. The abundance of age-1 fish is estimated from the age-0 trawls, as well as by MR methods.

Estimates of population abundance and trend from counts of fish derived from annual trawl surveys do not directly account for the number of additions (births) and losses (deaths) in a population. For example, a population exhibiting a death rate exceeding its birth rate could appear stable if it were maintained by outside recruitment. In contrast, estimates of abundance from open MR models are functions of survival rates and in situ recruitment (birth rates). MR model-based estimates are particularly useful because they can differentiate between a population that appears stable due to recruitment from outside the study area, from one that is (inherently) stable due to a balance between birth and death rates.

At this juncture, this discussion of sampling design options has been based on a rigorous application of methods firmly grounded in probability theory. However, there is a recognition that implementation of some of these approaches could require resources beyond those available to the Corps. A key question is whether it is possible to estimate an *unbiased* sample mean principally for age-0 Pallid Sturgeon in the extensive and dynamic Missouri River. The concept of an unbiased sample mean drives much of the statistical estimation in most areas of science.

Effectively, the assumption is that given enough samples taken from the "population" of interest, a mean from many independently estimated sample means will converge to the true but "unknown" population mean value. That convergence to the true population mean is the goal of the estimating equations in classical statistics and is the basis for the statistical definition of bias.

For dynamic ecological systems like the Missouri River, the ability to sufficiently sample and accurately estimate an unbiased population mean -- even for the LMR only -- presents a logistical challenge owing to the spatial inconsistency of fish catch, high numbers of zero catches, incomplete knowledge of how age-0 Pallid Sturgeon are clustered over space and time, and the influence of environmental conditions on fish catch rates. Improving upon the current design will require that these and other issues be addressed in continued engagements between the Fish Technical Team and ISAP.

As previously noted, targeted designs select sampling units using a subjective (non-random) approach guided by a mental model of the species and its habitat. An important constraint associated with targeted sampling is recognizing that selection bias, although assumed to be consistent if used for monitoring purposes, is also unknown. Selection bias could be associated with factors that vary over space and time that might include (1) the decision to target a particular site -- one biologist may be better than another at selecting sites with age-0 Pallid Sturgeon, (2) experience levels of the captain and crew who conduct the sampling, (3) subjectively chosen sampling units may not represent the entire population, and/or (4) habitat at a targeted site(s) can change over time, requiring new sites to be identified and included in analyses.

Despite the limitations of targeted sampling as a robust monitoring approach, it has served a critically important purpose in enhancing collections of age-0 Pallid Sturgeon and contributing to our knowledge of habitat attributes associated with this life-stage. Lessons learned through experience by the Pallid Sturgeon technical team can continue to inform the design of an efficient and effective monitoring program to support adaptive management of Pallid Sturgeon. In this context, future efforts employing targeted sampling should consider the important transition from a mental-model to a model-based design (SDM) that uses age-0 sturgeon habitat in developing a probability-based sampling approach. A robust sampling design, such as an SDM approach would reduce the zero-inflated data that are associated with random sampling. If *a priori* it was known from identified habitat attributes those sampling locations at which there are non-zero chances of capturing fish, then model-based probabilities can be assigned, and a probability-based sampling approach can be implemented. This knowledge has yet to be developed but could be a focus of future discussions between the Corps and ISAP.

How data can be analyzed to evaluate hypotheses and generate inputs to management decisions

Various sampling designs are appropriate for the estimation of abundance of age-0 fish. The current design is like a multistage design with simple random sampling at each stage. Other reasonable design-based include stratified sampling and adaptive cluster sampling. Both designs take advantage of spatial variation in fish abundance presumably driven by spatial heterogeneity in habitat quality. The estimators for sample unit means, population totals, and associated variances should draw guidance from multiple books including Thompson (1996) and Hankin et al. (2019).

Physical habitat variables associated with age-0 sturgeon collections should be included as covariates in the data analysis. For example, a metric of shear strength (difference in velocity between main and separated flow) may correlate with CPUE and help further refine our understanding of why age-0 fish congregate at specific locations. Relatedly, the model-based approach discussed at the November meeting (and above) uses predictions from a species distribution model to assign probabilities of occurrence or abundance to sample units based on environmental conditions. For example, a count-based SDM could use a Poisson regression model, where the log of the count in each trawl is regressed on a set of environmental covariates. The model-based selection probabilities (p_i for sample unit i) of candidate trawls could be used for stratification (stratified sampling design) or in terms of an unequal probability design. In the latter case, the selection probabilities (p_i) are used to estimate inclusion probabilities (π_i) according to $\pi_i = 1 - (1 - p_i)^m$, where m = sample size (24 trawls).

Unequal probability sampling (UPS) was discussed in terms of a species distribution model, that is, is model based. However, UPS is commonly considered as designed-based where differing inclusion probabilities result from some inherent feature of the sampling process. An example is from forest surveys to assess timber volume, where larger trees have higher inclusion probabilities.

The high mortality of Pallid Sturgeon at its early life stages is an important consideration when analyzing age-0 fish abundance data. Importantly, we wish to know if age-0 fish abundance is correlated to that of age-1 fish the following year (recruitment). Many age-0 Pallid Sturgeon collected in the LMR are small larvae (many <30 mm) that recently settled. At this stage, mortality can be high, and abundance may not correspond to year class strength. For example, a study of Lake Sturgeon in the St. Lawrence River system showed that high age-0 production did not necessarily lead to a strong cohort of subadult fish (ages 1-8); rather, the strongest cohorts there were associated with high river flows in June (Dumont et al 2011). Studies in the lower Missouri River have shown that stocked, age-0 Pallid Sturgeon can recruit to age-1 at relatively small size (~80 mm) although this could be less, since 80 mm was the lower range of hatchery fish that were initially stocked (Gosch et al 2022). Similarly, larval drift studies in the upper Missouri River have shown that small, 5-day post-hatch larvae (~20 mm) can survive to age-1+. However, release of 1-day post hatch fish (~11 mm) has resulted in no detectable recruitment to age-1 (P. Braaten, pers comm), illustrating how a 4-day difference in development and ~10 mm difference in size might affect survival and recruitment of age-0 Pallid Sturgeon.

Question 2: Given the proposed refinements in (1), what specific tasks do you recommend for the Fish Technical Team in FY23?

The lack of a defensible sampling design for age-0 (and age-1?) fish is the weak link in the current Pallid Sturgeon monitoring program. Deviations from probability-based sampling at stage 2 are not defensible and compromise reliable inference to the status and trends in age-0 fish abundance and to the magnitude of recruitment. As discussed above, alternative design options are available, but they require development of a habitat model to facilitate stratification or unequal probability sampling at stage 2. Moving forward, that could be a viable option for refinement of the age-0 monitoring program, given increased knowledge of habitat conditions associated with age-0 fish collections. The challenge would be in allocating the time and resources necessary to quantify and develop a habitat model for age-0 sturgeon. The worthwhile result of the effort would address many of the current monitoring shortcomings and enable an objective, habitat-informed random-sampling design for age-0 fish.

Available data currently used to assess Pallid Sturgeon populations derive from an imperfect sampling design. Nevertheless, raw data collected under the existing sampling design could be examined, analyzed, and otherwise evaluated with the objective of identifying potential flaws in the current monitoring program. Data from the stage 2 sampling units (trawls within macro-habitat) and data aggregated at the scales of bends and river segments should be used to calculate variances within and among those spatial components of the sampling hierarchy. The mathematical and statistical characteristics of the resulting variance estimates might shed light on the implications of the current monitoring program concerning accuracy and precision of current population metrics.

Moreover, existing data could be analyzed to describe quantitatively sample locations and associated habitat characteristics that reliably capture age-0 Pallid Sturgeon. This information could be used to create a model that describes the spatial distribution of productive sampling locations to increase efficiency (and reduce costs) in collecting numbers of age-0 Pallid Sturgeon sufficient to pick up signals from management actions. Similarly, data might be used to identify areas that are likely not habitat for age-0 Pallid Sturgeon – those areas can only add uninformative zeros to the monitoring data base. This is equivalent to redefining the sample frame to exclude non-habitat.

Quantifying the genetics of age-0 fish is a pre-requisite for identifying Pallid Sturgeon in collections of age-0 fish. Those data could serve other important uses in helping understand questions related to maturation schedules, particularly among females, or successful recruitment in specific year classes. A high proportion of age-0 siblings at certain locations or in certain years implies that reproduction may be driven by only a few mature fish. Conversely, a low proportion of or lack of siblings among age-0 fish could point to locations and years with greater numbers of gravid fish. Given the availability of that information, the Fish Technical Team might consider developing and testing hypotheses relating to successful reproduction -- keeping in mind that for female sturgeon, growth and condition the previous year may determine whether they produce eggs and spawn the following year. Genetics of age-0 fish could also be helpful in identifying successful recruitment of a year class. A sibling match between a wild age-0 fish collected at time T_0 with a fish collected at time T_4 indicates successful recruitment from that year class. That could prompt biologists to test hypotheses associated with recruitment dynamics.

As for the IRC discussion, the ISAP observes that there is not a defensible experiment regarding the efficacy of IRCs to enhance interception and rearing. The sample size at this point is simply too small from which any conclusions about the potential benefits of IRCs can be drawn.

The integrated Pallid Sturgeon population model (IPSPM) being developed by Mike Colvin was not discussed in detail at the MRRIC meeting; however, as previously mentioned, the model is secondary to first developing a defensible monitoring program focused on estimating fish abundance. At this stage, the IPSPM model may not be a critical component of the AM program. Under the umbrella of an adaptive management paradigm, the type of model that would be most useful is one that incorporates uncertainty arising from the observation process (e.g., CPUE of age-0 fish) and uncertainty in the state process. The latter source reflects temporal or spatial (or both) variation in the abundance of age-0 fish. Insights to system state (e.g., age-0 abundance) is estimated from the monitoring data, data characterized by counting and estimation uncertainty. To be useful for management decision-making, the monitoring data should be collected along with environment covariates hypothesized to drive variation in fish abundance and distribution.

Based on our current understating of Dr. Colvin's model, it is not clear how it will incorporate potential management actions into projections of population consequences for sturgeon. To make this link, the model will need to incorporate environmental factors that are likely to be affected and unaffected by management decisions. Those factors will need to be linked to survival and recruitment and ultimately to abundance. Relating environmental drivers to demographic consequences would advance what is currently known about the ecology of Pallid Sturgeon and provide value in management planning for the species. And then, the implications of targeted and probability-based sampling designs on the accuracy and usefulness of IPSPM results should be evaluated with related considerations of how variance in available monitoring data impact model results and their interpretation into adaptive management decision-making.

Question 3: How would the refinements under points (I.) and (II.) improve management decisions?

A robust, age-0 monitoring program would improve management decisions by empowering the Fish Technical Team with the ability to evaluate important management actions and/or environmental drivers that influence reproduction and recruitment of age-0 Pallid Sturgeon. Abundance estimates for age-0 fish would improve as well as the understanding of specific habitat factors and factor conditions associated with the occurrence of age-0 sturgeon.

There is a profound lack of information related to year-class strength. Does age-0 fish abundance correspond to year class strength? Or, do certain environmental factors play a larger role than early-stage abundance in determining the abundance of older fish? On the one hand, the general lack of wild, age-1 Pallid Sturgeon in the LMR implies that recruitment of age-0 fish to age-1 is negligible. On the other hand, uncertainty about the fate of age-0 fish produced in the LMR is high, given that downstream movement of young fish may carry them into the Mississippi River. Efforts to prioritize and increase age-0 sampling, combined with a robust monitoring program, can help answer those questions.

As emphasized in previous ISAP reviews, monitoring is essential to track changes in the state of the fish population and to track population responses to management through time (see Williams 2011). The essential role of monitoring is to contribute to decision-making and the monitoring program should emphasize that goal (Nichols and Williams 2006). However, monitoring can detect state changes only after they have happened -- it is not anticipatory. Monitoring is primarily a data- driven process and can occur absent a model of how sturgeon respond to environmental drivers. To project future changes to fish populations based on management actions taken today requires a forecasting model -- "Therefore, any approach to forecasting, from the simple to the most complex, requires the combination of models and data" (see Dietz 2017, page 4).

Question 4: How would you rank the order of importance of your recommendations?

The most urgent need is to address the deficiencies in the age-0 and age-1 monitoring program. Analysis of existing Pallid Sturgeon monitoring data should be undertaken to *understand the statistical limitations of the current monitoring design*, guide corresponding modifications to the current design, and facilitate the integration of data with the IPSPM. A sampling design that is well-grounded in statistical theory is essential in making defensible inferences to the state of the Pallid Sturgeon populations on the Missouri River. This has apparently been accomplished for older fish by means of well-developed capture-recapture (MR) models that provide model-based estimates of abundance, survival, and recruitment. Congruent with the need to improve the age-0 and age-1 monitoring program, *age-0 fish sampling should be prioritized in the lower Missouri River* to facilitate development of a habitat model and provide information that better informs the factors affecting recruitment to older ages. *Understanding the fates of age-0 fish produced in the lower Missouri River* remains an important challenge that must be met by considering the full extent of Pallid Sturgeon movement and its distribution in the lower Missouri River and Mississippi River. Further discussion and future engagements between ISAP and the Fish Technical Team on the topic is needed. *Development of a forecasting model that is clearly linked to the monitoring data would provide important insights into sturgeon populations dynamics*. Such a model would project system responses to natural environmental variation or management actions. It would allow for a comparison between observed fish responses, that is, the value of state variables from the monitoring data, to projected responses. A lack of concordance between observed and projected outcomes would lead to model revisions informed by the monitoring data.

Dr. Colvin's IPSPM model is a forecasting model. What is missing, is a clear link between the monitoring data, management actions (actual or anticipated), and model structure. The mark-recapture data are used to provide parameter estimates for the population model. What is unclear, however, is the extent to which parameter estimates in the model are linked to environmental factors effected by management decisions. It is also unclear how the model differentiates between missing values (inefficient sampling) from true zero values (samples from areas that are not Pallid Sturgeon habitat). The ISAP could use a document that clearly describes the model and how it is intended to inform the adaptive management process.

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