Glen Canyon Dam Adaptive Management Program
Protocols Evaluation Panel

Final Report for the
Fisheries Program Review

December 27, 2016

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Executive summary

The Grand Canyon Monitoring and Research Center (GCMRC) fisheries program convened an independent protocol review panel on August 2, 2016. The panel was asked to evaluate the quality and breadth of the monitoring and research conducted by the fisheries program in the Colorado River and its major tributaries.

The panel was very impressed with the quality of the fisheries-related research being conducted in the system and the high-quality peer reviewed publications resulting from these efforts. Project scientists and staff are to be commended for their hard work. The panel also believes that the program has made significant progress toward incorporating the recommendations from previous reviews. As a result, the program has compiled a wealth of data that can be used to quantitatively evaluate and refine existing research and monitoring efforts.

The fisheries program submitted five questions for the panel to consider. During the course of the review, the panel also identified management and institutional issues that potentially influence the effectiveness of the fisheries program going into the future. Answers to the questions and issues are summarized below.

The quality of the catch effort data from the rainbow trout, humpback chub, and system wide long-term monitoring is likely reduced due to the inability to account for incomplete capture. Monitoring data can be improved by increasing fish Passive Integrated Transponder (PIT) -tagging efforts and employing new or existing population estimators, such as Cormack Jolly Seber and mark-resight, to estimate vital rates and abundance.

Rainbow Trout fishery research has identified more questions than answers regarding the ecological mechanisms responsible for population declines. Given the complexity of the system, trout research efforts should consider, and if possible, incorporate all levels of ecosystem into their study and develop a conceptual model to place all existing hypothesis into a broader context.

The fish behavioral changes due to use of bait, handling, and marking can affect the accuracy of capture recapture estimators used to estimate humpback chub abundance in the Little Colorado River and translocation tributaries and should be evaluated. In addition, monitoring in the Little Colorado River and at translocation reaches should place a greater emphasis on evaluating the factors affecting vital rates using new or existing population estimators rather than focusing on abundance.

It was difficult for the panel to assess the success of the Humpback Chub translocation efforts because the objectives were unclear. The panel recommends that the program reconsider and clarify the goals of the translocation experiments. The reevaluation should also incorporate a new quantitative analysis of the effects of translocations on the donor population using the demographic parameters estimated by the program.

Given the wealth of data collected by the program, greater effort should be expended evaluating alternative sampling and monitoring designs and assessing tradeoffs with respect to program objectives. An evaluation of alternative designs also could be used to identify designs that minimize handling of fish and meet program objectives. In addition, the program should expand its efforts using PIT tag arrays or similar technologies to improve data quality while minimize handling of fish.

Expansions of exotic fish species populations have the potential to reverse recent gains in humpback chub populations. The panel recommends that the program consider developing a separate invasive species detection program that includes quantitative triggers and remedial actions.

The program should continue to engage angler groups by developing tools to enhance communication and understanding of the results of rainbow trout monitoring and research. The results of evaluations of alternative sample designs, tradeoffs, and the potential effects on fishes should be clearly communicated to Native Americans stakeholders. The program also should expand citizen science outreach efforts to include fish monitoring, if feasible.

Adaptive management as currently practiced by the program is hindered by the lack of control of management of key management drivers. The program should consider developing an adaptive management framework that is sufficiently flexible to accommodate opportunistic learning.

The panel suggests that the program develop of a more formal integration of monitoring and research within Lake Powell and the Colorado River below the Glen Canyon Dam. At a minimum, modeling of the potential impacts of quagga mussel on water clarity, nutrient conditions, and thermal structure should be considered.

1. INTRODUCTION

The Colorado River is a key resource supporting the diverse ecology, economy, and cultural heritage of the Southwest. As such, the success of the Glen Canyon Dam Adaptive Management Program (GCDAMP) in managing and integrating the portfolio of different uses is critical to the sustained conservation of the river and its inhabitants. As identified by the U.S. Fish and Wildlife Service biological opinion (BioOp), a primary focus of the adaptive management program (AMP) is to manage the effects of dam operations on the physical and biological resources of the Colorado River downstream of the dam. The primary biological issue is the status, trends, and conservation of the endangered humpback chub (*Gila cypha*; hereafter, HBC) population centered in the Grand Canyon in general and at the confluence of the Little Colorado River in particular. For the past decade, the major issue believed to be limiting this population has been recruitment failure reportedly due to some combination of predation of HBC young-of-year (YOY) by rainbow trout (*Oncorhynchus mykiss;* RBT) introduced to the cold tailwater of the Glen Canyon Dam above Lee's Ferry and other factors. However, the introduced RBT have become an important resource themselves, leading to an additional stakeholder-driven goal of managing the system to support both species in a spatially separated manner.

Robust and sound science is the foundation of the adaptive management process, which progresses from the identification and prioritization of issues and knowledge needs, to the selection of monitoring approaches and response variables, and includes the design of experiments and construction of models that allow decision makers to arrive at the most effective management strategies. The US Geological Survey, Grand Canyon Monitoring and Research Center (GCMRC) is the leading provider of scientific information used by the GCDAMP to inform the adaptive management of dam operations and the status of ecologically and economically important ecosystems to various program collaborators.

Periodically, the GCMRC convenes independent review panels to assess various aspects of the program including scientific soundness, data quality, and whether the program is adequately addressing research and monitoring needs of the GCDAMP. In 2016, the fisheries program initiated a review of their existing monitoring and research program by a protocol evaluation panel (PEP) that included 5 scientists with expertise in aquatic and landscape ecology, population estimation and dynamics, ecological modeling, fishery biology, and adaptive management. The review began on August 2, 2016 with a half day of formal presentations on topics that ranged from an historic overview of the Colorado River ecosystem to tribal perspectives on the river and the program, followed by a one-day field visit to Glen Canyon Dam reach above Lee's Ferry (Appendix A). During the field visit, the PEP interacted with GCMRC personnel, investigators from cooperating agencies including the Arizona Game and Fish Department and US Fish and Wildlife Service, independent scientists conducting monitoring and research in the area, and a number of stakeholders (primarily fishing guides). Attendees were transported to noteworthy locations along the river and provided with information on the issues associated with each location that included: the detection and removal of a concentration of an invasive sunfish; changes to the benthic macroinvertebrate community and the ‘bug flow’ hypothesis; changes in the benthic macrophyte community; and water quality, reservoir operations, and potential nutrient limitations. The PEP also was provided with a list of questions about the program by the stakeholders present (Appendix B). At camp, formal presentations were made by program and affiliated staff and agency cooperators on topics that included: the compilation and use of traditional ecological knowledge; the results of recent research on trout reproduction and movement; and ongoing and emerging invasive species issues. The remainder of the trip was filled with informal discussions among attendees focusing on the natural history of the reach, historic and emerging management issues, and the state of the science. The trip also served to provide PEP panelists with a realistic perspective of the challenges associated with conducting research, monitoring, and management activities in the area. After returning to Flagstaff, the remaining 1.5 days were devoted to formal presentations and discussion topics that included fish and benthic invertebrate dynamics, stakeholder perspectives of the program, and current monitoring efforts by the program and cooperating agencies. During the discussions, the Colorado River Energy Distributors Association also provided the PEP with a set of questions regarding current and potential GCDAMP activities (Appendix C). The PEP then met to discuss the review and next steps in the process.

Prior to and following the August meeting, the PEP was provided with background material, such as reports and peer-reviewed literature, and access to fisheries program staff who provided additional information on current and historic program activities. These were reviewed by the PEP and used in their assessment of the program. The fisheries program also posed a series of five questions to the fisheries program PEP. To fully address these questions and those questions posed by the stakeholders, required the consideration of multiple program objectives that include ecological, economic, and sociological values. Attempting to evaluate tradeoffs among all objectives for current program activities or potential changes in the future are beyond the scope of this evaluation. Rather, the practicable role of the fisheries program PEP was to evaluate the state of knowledge (i.e., the science), highlight successful efforts, and finally to make suggestions concerning results. Sections 2 - 6 of this report uses this approach to addresses the five topics requested by the fisheries program. During the course of the evaluation, the PEP also identified management and institutional issues that many influence the effectiveness of program activities. Sections 7-9 address these additional issues.

2. RAINBOW TROUT MONITORING AND MANAGEMENT

A Rainbow Trout (RBT) fishery was established on the Colorado River in the reach above Lees Ferry shortly after the completion of Glen Canyon Dam in 1964. Since then, the 25 km reach has garnered a national and international reputation as a blue ribbon recreational RBT fishery that is crucial to the local economy. The RBT fishery has been experiencing significant declines in recent years that could have a major economic impact if not reversed. Fishery scientists and managers have identified multiple factors that are potentially responsible for the decline in the RBT fishery. The non-native RBT also are believed to be one of the factors negatively affecting the endangered HBC in areas downstream of Lees Ferry at the confluence of the Little Colorado River (LCR). To minimize the potential harm of RBT on HBC, managers have developed abundance-based criteria that trigger management actions intended to reduce non-native trout (both Rainbow Trout and Brown Trout) abundance on reaches above and immediately below the LCR confluence. To effectively and efficiently manage the RBT fishery and minimize effects on endangered HBC, managers need information on the current status of and the factors affecting RBT in the reach above Lees Ferry coupled with estimates of the distribution and abundance of RBT in Marble Canyon, the area below Lees Ferry and in the vicinity of the LCR. Towards these ends, the GCMRC fishery program and cooperating agencies have conducted two loosely integrated RBT research and monitoring efforts in Glen and Marble Canyons.

The Arizona Game and Fish Department (AZGFD) has been conducting standardized electrofishing surveys during the spring, summer, and fall since 1991. This effort provides estimates of RBT catch per unit effort (CPUE) from a relatively large number of randomly selected sites in Glen and Marble Canyons. Program managers indicated that these monitoring data are primarily useful for evaluating long term trends in RBT populations and for evaluating *coarse* response to management actions (i.e., multiple years after implementation). The monitoring also provides information on fish body condition, growth, the age structure of the population (potentially) and whether CPUE-based management triggers have been reached. Because of the sample frequency and large spatial extent, these monitoring efforts also provide information on the occurrence and prevalence of other (i.e., non-trout) non-native fish species. Creel and angler satisfaction surveys also are conducted in conjunction with standardized electrofishing efforts. These surveys have been conducted since 1964 and provide information on the human dimensions of the fishery including angler catch and satisfaction, harvest rates, and economic benefits.

The other RBT sampling effort in Glen and Marble Canyons is associated with research into the factors affecting RBT population dynamics and dispersal and involves two types of sampling including 10 day trips twice a year throughout length of the Glen Canyon reach and quarterly sampling at one fixed site in Glen Canyon and 4 sites downstream of Lees Ferry. This Rainbow Trout Early Life Stage Study (RTELSS) sampling effort provides estimates of RBT population size and age structure that are adjusted for incomplete capture, population demographic rates (i.e., survival, reproduction, emigration), and fish growth and condition. These estimates can then be used to elucidate the relation between environmental and ecological factors (e.g., flows, nutrients, macroinvertebrate density) and RBT demography. The program managers and affiliated scientists indicated that these data are useful for evaluating the effects of management actions on RBT populations and dispersal at relative fine resolution, such as weeks and months. In addition, the abundance estimates are also used to determine whether RBT abundance triggers have been reached.

Each of these two efforts has strengths and limitations. To maintain a quality fishery it is necessary to understand the factors affecting vital rates, currently these estimates are only provided through the intensive research sampling efforts. Similarly, adaptive management (AM) requires the timely integration of monitoring data so that information about system dynamics (i.e., hypotheses) can be evaluated and updated quickly enough to improve management. The relatively long time period needed to detect changes (trends) in CPUE with the monitoring data also suggest that its use for adaptively managing the RBT fishery is currently limited. Minimizing the effects of the RBT and other exotic species (e.g., green sunfish) on HBC also requires information over a greater spatial and temporal extent. The AZGFD monitoring is providing a robust view of status and trends of exotic species across the entire area, whereas the more intensive research monitoring efforts of the RTELSS have a smaller spatial extent. However, the RTELSS efforts indicate that the AZGFD monitoring data also are systematically biased due to heterogeneity in capture probability that varies with conditions during sampling and fish population size. Based on discussions with angler stakeholders, it also appears that the RBT population estimates and trends produced by the AZGFD and RTELSS efforts are either misunderstood or not believed by the stakeholders.

The degradation of the RBT fishery in the Lees Ferry tailwaters would have a major economic impact and potentially influence how the US Bureau of Reclamation (USBR) would manage Glen Canyon Dam. While RBT are not native to the Colorado River system, fisheries ecology may be able to help provide a management recipe for maintaining this economically important resource. The program has identified several factors that are potentially responsible for the declines including changes to the hydrologic regime; reduced benthic macroinvertebrate productivity due to dam operations; and reduced system productivity due to decreased nutrient inputs. However, none of these hypotheses has been fully tested. The recent work on the role of benthic invertebrate community composition and production on the RBT population dynamics is potentially a step in the right direction. The resulting proposal to run an experimental 'bug flow' to evaluate whether the current hydropeaking pattern used by Glen Canyon Dam is the ultimate cause of the decline in fish production fits well in the AM framework

The PEP believes that the current RBT monitoring and research activities are high quality and critical to the objectives of the program. After reviewing the publications, presentations, and in conversations with program staff and cooperators, the PEP identified a few changes that could improve current efforts and potentially fruitful avenues to focus future research efforts.

- The program should continue to monitor trends in RBT relative abundance, growth and condition. The PEP believes (1) that it is essential to maintain the integrity of the long-term monitoring data collected by AZGFD but also (2) that the program needs to build on this long-term monitoring effort to estimate the annual response of RBT to conditions. Therefore, the program should consider and evaluate the feasibility of the following modifications to provide additional insights and improve data quality.
    - RBT collected during the seasonal monitoring efforts by AZGFD should continue to be tagged with PIT tags or similar tags. This would allow for estimation of demographic parameters using open-population estimators, such as age structured, multi-strata, Cormack-Jolly-Seber (Williams et al. 2002). These methods do not require any additional sampling effort, other than marking, and can be employed using the existing sample design.
    - Tradeoffs, such as the number of fish that need to be tagged vs. the additional time required for tagging and precision of estimates, could be evaluated using

simulation. PEP is confident that the program staff have the skills for such an evaluation.

  - Estimates of recapture probabilities and availability calculated from open population models may be useful for adjusting the catch data to provide RBT abundance estimates and unbiased or minimally biased age-structure estimates.
  - The program should continue to develop protocols for incorporating antenna arrays suitable for detecting PIT tags into their monitoring and research activities. This would potentially decrease the amount of fish handling without comprising the estimation of demographic parameters, such as survival and movement. In addition, the antenna array detection data may be useful for getting better estimates of RBT population size using mark-resight (or similar) estimators (McClintock et al. 2008).
  - The PEP recommends that feasibility of the modifications suggested above and throughout this document should be evaluated (e.g., through simulation) prior to their adoption using estimates of demographic rates and capture probabilities generated by the program.

- The program should continue its important research into the factors affecting RBT population dynamics. These efforts are somewhat hindered by the complexity of the system being studied and the minimal ability of the fisheries program to control system drivers (e.g., flows). The PEP believes that there are a few topics that should be improved.
  - Given the complexity of the system, RBT research efforts should consider, and if possible, incorporate all levels of ecosystem into their study (e.g., nutrients, benthic macroinvertebrates, temperature, Lake Powell management and dynamics).
  - Emigration of RBT to downstream reaches may be related to the abundance and relative condition of the population and should be considered for evaluation.
  - The program should consider using a RBT specific conceptual model to place all existing hypotheses into a broader context and to help identify other drivers (e.g., river-reservoir nutrient dynamics, seasonal high/low flows, density-dependent or

other intrinsic population controls) that are potentially as important to RBT population sustainability. The conceptual model also will facilitate communication within and outside the program.

3. HUMPBACK CHUB MONITORING AND MANAGEMENT

Monitoring activities focused on Humpback Chub (HBC) provide valuable information on the size of the population in the LCR confluence area and elsewhere in the canyon. This information is of high priority because if low abundance is observed, this will elicit management actions to help restore the population. Monitoring also incidentally serves to alert the scientific community of the occurrence and abundance of nonnative species that might overlap spatiotemporally with HBC populations. Finally, documenting the occurrence of HBC aggregations is valuable in understanding the feasibility of habitats other than the LCR confluence to support populations of HBC.

Research priorities of the program have focused on determining vital population dynamics through an age-structured multi-strata population model for HBC at the LCR confluence, using capture-recapture studies to identify and model dispersal of HBC between the LCR and mainstem Colorado River as well as elsewhere, and mesocosm experiments testing the effects of temperature and turbidity on predation of HBC by trout.

The PEP considers the current monitoring and research activities to be high quality (as evidenced by peer-reviewed publications) and of considerable importance to the overarching goals of the GCDAMP. During the PEP review, a number of presentations were given and ideas presented that were noted as particularly valuable areas for monitoring and research.

- <u>Quantifying impact of trout predation on natural populations of HBC.</u> - It was well demonstrated through diet analysis and mesocosm experiments that trout can prey on HBC, but it is much more difficult to evaluate the importance of trout predation on HBC at a population level in the canyon. Can the data collected (e.g., trout predation and abundance) be incorporated into the multi-strata models to evaluate the potential for trout predation to result in a critical decline in HBC population? Data are already available to at least develop some scenarios that could be used to evaluate the effect of trout. The ability of rainbow trout to negatively affect HBC populations is difficult to demonstrate.

- Continuing efforts to find and document other reproducing populations of HBC in the canyons is of considerable importance and is encouraged.
- Efficiency of HBC monitoring and research might be improved by enhanced coordination among agencies and sampling efforts, as well as by power analyses to optimize sampling effort.
- Some potential suggestions for monitoring trends in HBC abundance, growth and condition are to use open-population estimators or preferably, the robust design, using PIT tagging of fish (during each survey) to get abundance, survival and movement.
- For baited hoop netting, researchers should investigate whether baiting affects fish behavior, particularly if using Chapman - Lincoln - Peterson mark-recapture estimates that require assumptions of constant capture probability (e.g., see Peterson et al. 2015).
- There was discussion among the PEP if enough resources were available to continue current intensive monitoring efforts at the LCR confluence as well as expand to another site? If so, is it necessary to sample on a seasonal or annual basis? Could sampling of population dynamics occur in alternating years to allow intensive sampling at multiple sites? How much information is gained with seasonal sampling? Could a simulation based on a resampling approach be used to evaluate the importance of sampling intensity?

HBC translocation research

Efforts since 2003 have involved translocating HBC from the core population in the LCR to sites upstream in the LCR (Chute Falls), Havasu Creek and Shinumo Creek. Additionally, fish have been moved to the U.S. Fish and Wildlife Service Native Aquatic Resources and Recovery Center (ARRC) to maintain a “genetic” refuge population. The data on the success of these translocations are equivocal, but data on growth rate and evidence of reproduction in Havasu Creek suggest the possibility of establishing populations of HBC. That said, a large number of fish emigrate from the tributaries and uncontrollable events (i.e., wildfire) have caused the elimination of others.

PEP recommended prioritization for HBC translocation efforts.

- The main objectives of the translocations are to supplement or establish new populations. Based on the translocations to date, it is still not clear if this is a feasible management activity. It would be useful to reconsider the goals of the translocation experiments to guide future efforts. It appears the translocations can have a number of potential roles that might include: 1) establishing a new reproducing population; 2) providing nursery habitat to raise juvenile HBC to a large enough size to escape predation, 3) provide a refuge population; and 4) increase the genetic diversity of supplemented populations.

- Could high emigration rates be mitigated by using alternative stocking methods (different sizes of stocked fish or acclimation periods)?
- Continued monitoring for evidence of reproduction by translocated individuals and quantifying emigration, through remote PIT antenna are valuable projects that will help evaluate the success of the program.
- A relatively large number of HBC have been translocated with no apparent harm to the core population. The effects of translocating individuals were evaluated using a population viability model before the recent development of the integrated population model. The PEP suggests that the program use the new integrated population model to evaluate potential harmful effects on donor populations. This model also could be used to assist decision making under adaptive management.
- The genetic considerations of translocations or refuge populations at AARC do not seem to be very well developed. Has the genetic diversity of HBC populations been thoroughly assessed and are there strategies to maintain genetic diversity within and among populations in the canyon? If it turns out that sub-populations of HBC are genetically distinct, you could maximize genetic diversity by intermixing the populations. However, mixing populations may not be a good idea if local adaptation is somehow beneficial.

Additional reproducing HBC populations

One important outcome of the spatially extensive fisheries monitoring programs has been the identification of a discrete population of HBC far downstream of the Lower Colorado River (LCR) population, as evidenced by the consistent capture of a small number of YOY and juvenile HBC in this downstream reach. The significant spatial gap in the occurrence of earlier ages implies that there may be a second population of HBC, however conclusive evidence is lacking at this point. Because of the implications for the conservation status of this species, the

PEP encourages the fisheries program to consider a project that could provide a more definitive answer of whether this might be a second population.

4. EVALUATING TRADEOFFS IN MONITORING EFFORTS

Power Analysis Review of Monitoring and Research Studies

The program conducts various monitoring and research projects to address important issues. Examples include both emerging issues (e.g., quagga mussels, non-native warm-water fishes) and those recognized to be increasing in their importance (e.g. establishment of one or more additional populations of humpback chub), which require additional resources. Given budgetary constraints, it is important to identify areas within existing projects where resources may be reallocated without compromising ongoing and essential monitoring and research. Existing studies and monitoring often include sampling at many locations and sometimes multiple times per year. Having had many of these field studies underway for multiple years, the program is in an enviable position of having extensive datasets that provide information necessary to determine the degree of sampling adequacy (e.g., power analysis).

- The PEP recommends taking advantage of datasets from both long-term and short-term studies to conduct power analyses or sampling simulations to determine whether a reduction in the frequency of sampling (e.g., two rather than three sampling periods per year, alternating years rather than annual sampling) or reductions in the number of individual fish handled (e.g., tagging) would provide the information necessary to achieve objectives for monitoring and research while freeing up valuable resources (both financial and human capital) that can be deployed to address these emerging and upcoming issues. By contrast, such an examination may highlight monitoring or research studies that have inherently high variation and limited ability to detect variation or change in attributes of interest (e.g. trends in population abundance). In such cases, the monitoring needs to be carefully assessed to determine whether increased resources should be applied to the field study, the study design should be modified, or that aspect of monitoring be discontinued. The 2009 PEP report discussed issues related to power analysis with regards to a limited number of aspects of the overall program. The PEP suggests a thorough examination of the various sampling programs in this manner to maximize efficacy and overall scope of work that can be undertaken within the program. Capitalize on the wealth of data now available in order to better assess allocation and redeployment of effort where appropriate.

An additional benefit of identifying appropriate reductions in the sampling and handling of fish, or providing increased justification for the need for particular levels of sampling (whether decreases, increases or *status quo*), is that it will help address one of the concerns raised by Native Americans, as discussed below (Section 6). Furthermore, the clear demonstration of the need for particular levels of sampling to achieve required outcomes (e.g., legal obligations under the ESA or priorities determined by the Department of the Interior) and such an evaluation of existing programs may strengthen the case if requests for further resources (i.e., budgetary increases) are needed.

5. MONITORING BROAD-SCALE FISH COMMUNITY STATUS AND TRENDS

Broad-scale monitoring of fish community trends in the Grand Canyon is primarily accomplished through the System Wide Electrofishing Project, a collaboration among the Arizona Game and Fish Department and the U.S. Geological Survey. During the PEP meeting at the GCMRC in August 2016, there was considerable discussion about the relative merits of continuing the current System Wide Electrofishing Project with its emphasis on CPUE data, or switching to a more intensive but less expansive sampling effort that would generate population estimates. A major concern with CPUE data is that the assumption of equal catchability of a species among sites and years is often violated when sampling the Colorado River in the Grand Canyon. The primary factors that affect catchability when electrofishing in the Colorado River are high water turbidity that makes it difficult to see immobilized fish, high river discharge that reduces the areas that can be effectively/safely sampled, and inexperienced crew members that reduce netting success (Rogowski et al. 2016). In addition, presentations by program staff indicated that the effects of stream habitat characteristics affect catchability. These factors are difficult to control, hence CPUE data will continue to be noisy.

The PEP supports the conclusions of two previous external review panels that spatially expansive, long-term sampling with standardized techniques is a valuable tool for tracking changes in fish assemblages throughout the mainstem Colorado River in the Grand Canyon (Anders et al. 2001, Bradford et al. 2009). Such monitoring can detect relatively large changes in fish abundance and can document range expansions of nonnative species that inhabit mainstem habitats. Switching to a mark/recapture sampling effort would make it easier to detect changes in abundances of individual species. The trade-off would be sampling at fewer sites since a minimum of two nights would have to be spent at each site to provide for a marking event and at least one recapture event.

A compromise would be to implant fish collected during the system-wide electrofishing effort with PIT tags. This would allow for estimation of abundance and demographic parameters using open population estimators, such as age structured, Cormack-Jolly-Seber models (Williams et al. 2002). These methods do not require any additional sampling effort, other than marking, and can be employed using the existing sample design. PIT-tagged fish could be recaptured during subsequent system-wide electrofishing efforts and by the use of portable PIT-tag antenna units recently developed by Marsh and Associates, LLC. This design would also allow for the abundance estimation using a mark-resight estimator (McClintock et al. 2008). The PEP encourages continuing and expanding the use of portable PIT-tag antenna units during the system-wide electrofishing efforts. In addition, the GCDAMP could consider deployment of portable PIT-tag antenna units by rafting guides as part of a citizen science/outreach effort.

Current system-wide electrofishing by AZGFD is considered effective at capturing nonnative species know to be present, such as rainbow trout, brown trout and common carp, and will likely be effective at sampling some potentially invasive species such, as walleye and smallmouth bass. But channel catfish, bullheads, striped bass and small-bodied fishes are not effectively sampled by this method (Hilwig and Andersen 2011). Also, the AZGFD sampling uses a stratified random design to allocate sampling locations each year – thus sites important as entry points for invasive species may not be sampled yearly. For example, the area around the confluence of Bright Angel Creek was not sampled in 2014, despite the importance of this tributary as a source of brown trout to the Colorado River (Rogowski et al. 2015). For these reasons, the PEP recommends that a separate invasive species detection program be considered. This separate program would use a variety of sampling gears deployed at fixed sites where nonnative fish are known to exist or where introduction is most likely to occur. Such an invasive species monitoring program could build upon the strategies proposed by Hilwig and Andersen (2011).

Areas targeted for invasive species monitoring should be sampled using the "slow" electrofishing techniques described for nearshore habitats by Korman et al. (2015) and other gear such as seining, minnow traps and hoop nets (Hilwig and Andersen 2011). Detecting young of year of recently introduced nonnative species should be a goal of this monitoring because it would signal the potential for further spread and population increases of invasive species that could harm native fishes.

Four areas should be intensively monitored for occurrences/increases in nonnative fish populations.

1) Glen Canyon from Glen Canyon Dam to Lees Ferry, including the large, warm backwater area known as the 12-mile slough. Potentially invasive fish species that could colonize the Grand Canyon from Lake Powell include gizzard shad, white sucker, walleye, green sunfish, northern pike and smallmouth bass. Smallmouth bass would be of particular concern as this species is highly piscivorous and has harmed native fish assemblages in other parts of the Colorado River drainage (Johnson et al. 2008; Hilwig and Andersen 2011).

2. The Little Colorado River and its confluence with the Colorado River. This area is critical habitat for the humpback chub. The lower, perennial portion of the Little Colorado River already harbors several nonnative species such as channel catfish and common carp that could have negative effects on humpback chub. In addition, this section of the LCCR is occasionally colonized by other nonnative species that are flushed downstream during high flow events in upper portions of the LCCR watershed (Stone et al. 2007).

3) Bright Angel Creek and its confluence with the Colorado River. Bright Angel Creek is considered to be a hotspot for brown trout recruitment in the Grand Canyon. Brown trout are more piscivorous than rainbow trout but their overall effect on the humpback chub population is lower because brown trout are believed to be less abundant than rainbow trout in the CRe. Any change in river conditions that would allow brown trout to increase would therefore be highly detrimental to humpback chub throughout the CRe.

4) The Colorado River where it flows into Lake Mead. The Lake Mead fish community is dominated by warmwater, nonnative species including piscivorous species such as striped bass and channel catfish that could be detrimental to native fish populations in the Colorado River. Because these nonnatives could easily move upstream with warming

climate, the Colorado River inflow to Lake Mead is considered to be area where introduction of new species is likely to occur (Hilwig and Andersen 2011).

In addition to above four areas, the PEP recommends that other invasion hotspots also be monitored such as warm spring inflows and near mouths of tributary streams known to contain populations of nonnative fish species. These recommendations mirror those of Hilwig and Andersen (2011).

PEP recommendations regarding monitoring of broad scale fish community status and trends:

- Continue the system-wide electrofishing project in place since 2000 and PIT-tag fish before release.
- Use information on recaptures of PIT-tagged fish (obtained by electrofishing and from portable PIT-tag antenna units) to estimate population abundances and demographic parameters from open population estimators, such as age-structured, multi-strata, Cormack-Jolly-Seber models (Williams et al. 2002).
- Develop a separate invasive species detection program using a variety of sampling gears at fixed sites where nonnative fish are known to exist or where introduction is most likely to occur.
- Identify nonnative fish population or distribution (occupancy) indices or rules sets that would trigger nonnative fish control options to be deployed.
- Develop ways to routinely solicit information from fishing guides and anglers regarding the composition of the recreational fishery. Such information could serve as an early-warning system for changes in the distribution and population size of nonnative sportfish that are potential threats to HBC, especially brown trout.

6. MINIMIZING EFFECTS OF PROGRAM ACTIVITIES ON FISH WELFARE

We commend the fisheries program for their awareness and consideration of the diverse and often conflicting cultural and economic needs of the many stakeholders in the AMP process. In particular, efforts to substitute quantitative methods that reduce the mortality and handling of fish in the Colorado River (e.g., embracing hydroacoustic monitoring methods or automated [Vemcotype] telemetry, e.g., Scheerer et al 2015) into data collection for capture-recapture population models will likely increase the useful data as well as decrease objectionable actions.

These issues and differences in approaches are not restricted to this location and do include some fundamental differences in philosophies and approaches – there can also be differences within both the western scientific and Native American perspectives. The PEP was encouraged by the willingness of all parties to discuss issues and work towards solutions. Such willingness and engagement does not occur in all situations and it appears that there has been progress over time to foster these interactions. The PEP has suggestions to help further reduce concerns by Native Americans and enhance interactions.

- Use power analyses and simulation associated with the various monitoring and research programs to help determine ways to reduce the number of fish that may need to be captured and the associated work needed on individual fish (e.g., Peterson et al. 2015). This will provide better justification for the numbers of fish that need to be sampled, potentially reduce costs or allow reallocation of efforts to other priorities, and demonstrate a recognition of the importance of life within the river and willingness to modify sampling programs to achieve the required goals while minimizing impacts on the fish.
- There may be the potential to acquire some necessary tissues (e.g., otoliths for natal origin studies) from humpback chub through means other than sacrificing HBC individuals. It may be possible to acquire some HBC samples through non-lethal gastric lavage of other fishes (e.g., striped bass or trout) that may have eaten chub. At present it is unknown how many chub individuals, already dead, may be sampled in this manner but this approach may provide an option to minimize the number of humpback chub that will need to be euthanized to accomplish the goals of the natal origins study.
- Engage Native Americans in the monitoring and research programs on the river when possible to further strengthen connections between the various stakeholders, help reduce barriers to understanding by all parties, and provide valuable employment and training opportunities.

7. PROGRAM COMMUNICATION AND OUTREACH

The GCDAMP has a daunting task to address complex scientific questions while being sensitive to a diversity of stakeholder interests. Communicating the results of different tasks and projects in professional presentations and peer-reviewed publication is certainly necessary for scientific legitimacy; however this is not sufficient for a program like the GCDAMP. Establishing a clear framework so that peer scientists as well as stakeholders can understand how priorities are set, the logical sequence of experiments and projects, and how all of the different data and insights, past, present, and future, fit together is crucial. The use of conceptual models has been essential for facilitating communication and transparency for other similarly complex programs including the Everglades Restoration, the Sacramento-San Joaquin Delta Restoration Project, and the USACEs Missouri River Restoration to name a few. While an integrated conceptual model promotes better planning and decision making in the science process, the process of developing such a model alone is often extremely valuable for educating all the stakeholders and constituencies on progress, failures and what is learned from both. Because of its critical role in building transparency and trust, as well as facilitating the communication of results to the regional stakeholders, the Federal leadership and the cooperating agencies, and Congress, the PEP recommends that the program and its stakeholders make the development of an integrated conceptual model a top priority for the fisheries program. The focus of such an effort should be on outlining both the established and hypothetical interactions among drivers, stressors, and response variables of the Grand Canyon socio-ecological system.

In discussions with angler stakeholders, it was apparent to the PEP that there were some areas of disagreement with program staff and affiliated scientists about the state of the fishery and the factors affecting it. To address these issues, the PEP recommends that the program establish a process for engagement and communication with anglers with an emphasis on two different areas.

- The development of a population metric or set of metrics for characterizing the RBT population that are understood by and acceptable to the angler stakeholders.
- Continue and expand citizen science outreach efforts such as those used to monitor insect emergence throughout the canyon by rafters (Kennedy et al. 2016). New opportunities could include having guides on rafting trips employ portable PIT tag readers to collect data on fish locations and having fishing guides report catches of species of special

concern (e.g., more frequent occurrence of brown trout in the Lees Ferry area or the appearance of smallmouth bass in the fishery).

8. ADAPTIVE MANAGEMENT

There are two primary approaches to adaptive management that have been defined as the resilience-experimentalist approach and the decision-theoretic approach (McFadden et al. 2011). The major difference between these approaches is the role of experimentation in the learning process. The resilience-experimentalist approach relies primarily on experimental manipulation of the system to learn about how the system works. This approach employs the scientific method with the development of falsifiable hypotheses, the implementation of the experiment (management action), and the evaluation of hypotheses with the use of monitoring data. In contrast, the decision-theoretic approach facilitates learning through the integration of management and monitoring in a decision-theoretic framework. That is, a predictive model or set of models are created that represent alternative ideas of how the system works. Learning then is accomplished by comparing predicted outcomes to actual outcomes as measured by monitoring data. Decisions that increase the rate of learning (experiments) also can be incorporated into the decision-theoretic approach. From the beginning of the program, the GCDAMP has employed the resilience-experimentalist approach to adaptive management. This approach, however, requires that the implementation of the experiment be under the control of the program. During discussions with program staff, it was clear that many of the management decisions are heavily influenced by other GCDAMP objectives that may not be directly related to and even in conflict with fish program objectives. The best example of this was ending the experimental reduction of RBT inhabiting the reaches near the confluence of the LCR before the experiment was complete. This lack of experimental control and consistency in the application of treatments has hindered the adaptive management process for the fishery program. For instance, when queried, program staff indicated that learning was primarily opportunistic and there were few if any hypotheses that have been falsified or eliminated. To take advantage of these learning opportunities, the PEP recommends that the fish program adopt the decision-theoretic approach to adaptively manage the RBT fishery and HBC population in the LCR and confluence. The adoption of a decision-theoretic adaptive management approach would not require a new major research effort and could be accomplished by completing the following steps.

- Modify the existing integrated RBT population model to incorporate alternative hypotheses of the factors affecting survival, growth, emigration, and recruitment. This could be facilitated by the development of a conceptual model.
- Modify the existing integrated HBC population model to incorporate alternative hypotheses of the factors affecting demographics.
- Formally integrate the two population models to facilitate assessing the potential effects of RBT on HBC and the potential effects of system wide factors (nutrients, flow) on both species.

The one research area of the fisheries program that appears to be under their greatest control is the ongoing experimental management involving translocation of HBC within the LCR and to other tributaries. After reading the reports and publications and discussion with translocation project staff, it was unclear what key uncertainties (unknowns) the project faces, which alternative management actions (experiments) are available to the project (i.e., feasible), and what the alternative hypotheses of system dynamics might be. To minimize confusion and facilitate communication with stakeholders and other outside the program, the PEP recommends the following points.

- The fisheries program needs to develop clear set of alternative hypotheses regarding the factors responsible for the success or failure of HBC translocations.
- The hypotheses should be linked to specific management actions and descriptions of the criteria and methods that will be used to conclude that a hypothesis is falsified or supported. For example, what criteria define a successful translocation?
- These should be accompanied by steps that will be taken following the evaluation of hypotheses.

9. EMERGING ISSUES

9.1 Enhanced Integration of Reservoir and Lees Ferry Ecosystem Monitoring and Research

Conditions within Lake Powell directly affect conditions in the Colorado River below the Glen Canyon Dam, through alterations in water temperature, turbidity, and nutrient levels. The waters of Lake Powell and the Colorado River above Lake Powell also serve as biological reservoirs for additional exotic fish species (e.g., smallmouth bass, northern pike) that currently have been limited potential to colonize downstream due to the hypolimnetic (cold, deepwater) discharge from Lake Powell and the cold river water immediately downstream of the dam. There is clear recognition that reductions in water levels within Lake Powell presents an ecological risk downstream due to the potential for water releases shifting from hypolimnetic to epi- or metalimnetic regions of the reservoir. Such releases will be of water warmer and lower in nutrient levels than water released currently, which will be detrimental to the trout fishery. Warmer temperatures will potentially increase the likelihood of downstream dispersal and establishment of nonnative species such as smallmouth bass.

Quagga mussels have established within Lake Powell. Discussions during the PEP visit indicated that the program has evaluated the potential threat to the river ecosystem by quagga mussel establishment in the river below the dam. Given the rate of flow and sediment surface area available, it has been estimated that quagga mussels would effectively filter about 10% of the river water and therefore are not considered to pose a significant risk to the river food web. The PEP believes that this estimate is likely too low and is concerned that quagga mussels in Lake Powell could have a greater effect on the trophic dynamics of the downstream river ecosystem.

Lake Powell is a large, deep body of water and during the PEP visit, it was suggested that due to its physical dimensions it is not likely to be impacted by quagga mussels in contrast to smaller lakes or even Lake Erie (which has a relatively shallow western basin). Since the establishment of zebra and quagga mussels in lakes Michigan and Ontario, associated issues have developed related to off-shore (pelagic) declines in nutrient levels, large-scale declines in important food-web components such as the amphipod *Diporeia*, and increasing frequency of algal blooms in the nearshore areas – all factors in reshaping the food web and fisheries of these lakes. In conjunction with the decline in offshore productivity (reduction in total phosphorus and chlorophyll *a*) there has been an increase in water clarity (e.g., spring Secchi depth can be 2-3 time greater in Lake Michigan since dreissenids establishment) and an alteration of thermal structure (deepening of the mixing zone and warm epilimnetic zone; Cuhel and Aguilar 2013). As Lake Michigan and Lake Ontario both greatly exceed the area, volume and depth of Lake Powell, a potential outcome of quagga mussels in Lake Powell may be a similar reduction in offshore nutrients and production, increased light penetration and a deeper layer of warm water.

Given current concerns about the reduction in reservoir depth and discharge of warmer waters, the potential for quagga mussels to further increase the probability of warmer water discharges with concomitant reductions in nutrient levels presents significant but unquantified risk to downriver ecological resources (e.g. the likelihood of such an outcome is currently unknown but the significance of the effects could be very high). Direct impacts to the trout fishery through the increased water temperature and impacted food web via reduced nutrients and indirect effects of heightened potential for additional non-native warm-water species to disperse past the dam and establish downstream represent significant concerns to the humpback chub, trout and other species. At present there is some monitoring of conditions within the reservoir, but little to no research underway to determine the potential impact of quagga mussels within Lake Powell and the resulting effects downstream.

Water is essential in the arid west and large areas of the region are experiencing substantial changes in the water cycle; the Colorado River basin is no exception. Reduced inflows from their headwaters have caused reservoirs to be managed differently or behave in ways that are outside their original design parameters. In particular, the very low reservoir water levels have the potential to change conditions in tailwater systems. However, there is no clear understanding of either the sort of changes that can be expected if the current water balance trajectories continue or how these changes might influence attributes of either the cold tailwater or the warmer Colorado River further downstream.

- The PEP suggests the development of a more formal integration of monitoring and research within Lake Powell and the Colorado River below the Glen Canyon Dam. At a minimum, modeling of the potential impacts of quagga mussel on water clarity, nutrient conditions, and thermal structure should be considered. Integrating these findings with those regarding future water-level scenarios will provide a means to develop some risk scenarios for the resources downstream.
- During discussions in the field, project scientists indicated that detection limits under ongoing water quality monitoring were based on State Water Quality Standards and may be too coarse for ecological investigations. The PEP suggests that the program review the sensitivity of existing water quality monitoring and revise if necessary to ensure that sensitivity of the measurements are appropriate for program needs.

- Finally, we suggest that effort could be placed on modeling future scenarios based on the best available data from past conditions in Lake Powell.

9.2 Invasive species

Invasive species can have profound and long lasting ecological effects that are frequently beyond our ability to manage. The recent discovery of a concentration of YOY Green Sunfish (*Lepomis cyanellus*) and the GCDAMP response highlights three critical points about the arrival of a major invasive species: they are nearly impossible to predict with any accuracy; they are often only identified after the fact and by chance; and a large multiagency control efforts can work but are incredibly complex to execute and likely distract from other planned management actions (e.g., planed flow releases). Prevention is by far the more economically effective approach. With the presence of warm water habitats and a pool of potentially detrimental warmwater invasive species upstream and downstream of the main HBC population, invasive species outbreaks may be the fisheries program's most immediate risk.

9.3 Shifts in benthic macrophyte community

In addition to the more obvious threat posed by the invasive warmwater fish, the panel notes the recently observed shift in aquatic vegetation, from a community that was predominately *Cladophora glomerata* in the early 2000s to a community dominated today by bryophyte species in the tailwaters in the Lees Ferry reach and we encourage investigation of this phenomenon. Despite the importance of submerged aquatic vegetation in regulating many aspects of coldwater systems, it may also influence important aspects of the Colorado River system linked to adaptive management issues including nutrient cycles and habitat for a declining benthic invertebrate community. The consequences of such a major shift in a primary producer in an otherwise low productivity, arid region river seem to have been given little attention. Although the shift is already completed, we encourage the fisheries program to consider capturing what knowledge of the prior conditions exists as well as consider exploring and modeling what the trophic, food web and habitat impacts-constraints of the current dominant species might be on the tailwaters and downstream Colorado River (e.g., nutrient assimilation and stoichiometry dynamics, differences in secondary production of benthos).

9.4 Mitigating the effects of climate change

The proliferation of nonnative, warmwater fishes in Grand Canyon has been limited by the cold water released from Lake Powell. However, warmer air temperatures, reduced inflows and perhaps higher water clarity associated with quagga mussels will increase the temperature of water being discharged from Glen Canyon Dam into the Colorado River. A glimpse of such future conditions occurred in 2005 when a hot summer and drought conditions resulted in discharged water temperatures several degrees warmer than in other years. Although warmer water may provide a bioenergetic benefit to native species, warmer water would almost certainly allow colonization and expansion of nonnative warmwater native species likely to have negative effects on humpback chub and other native fish species. Actions involving the discharge of water from Lake Powell could mitigate the negative effects of warming temperatures. The PEP recommends that the program investigate the possible effects of temperature control device operation (in Glen Canyon Dam) on the factors directly influencing RBT and HBC populations (e.g., facilitating exotic fish species immigration) and indirectly by influencing other emerging issues like macrophyte shifts, benthic invertebrate productivity, and nutrient dynamics. This could be done through either bioenergetics- based assessments built on the multi-stage life history models or through simulation models. The design of these studies and communication/integration of the results into the adaptive management program would benefit greatly from development the conceptual models recommended earlier.

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Appendix A. 2016 Protocol Evaluation Panel - Fisheries Program Review agenda.

Start	End	Topic
Tuesday, August 02, 2016		
8:00	8:30	Welcome, introductions, workshop agenda, goals, ground rules
8:30	8:50	Historic Colorado River ecosystem and fish
8:50	9:30	Program overview, fisheries issues and policies
9:30	10:00	Tribal perspectives
10:00	10:15	Break
10:15	11:00	Rainbow trout population dynamics and early life history studies
11:00	11:45	Arizona Game and Fish Lees Ferry Rainbow Trout Monitoring and Creel
11:45	14:00	Travel to Lees Ferry
14:00	18:15	Boat safety orientation, Boat trip up-river, with presentations at stop-points
18:15	19:30	Disembark at campsite, campsite orientation, dinner
19:30	20:30	After dinner discussion, Natal Origins and trout movement
Wednesday, August 03, 2016		
8:00	9:00	Informal discussion: Emerging issues: Green Sunfish, Brown Trout
9:00	1300	Break camp and return to Flagstaff
13:00	13:20	Formal presentation, with discussion: Food base
13:20	13:40	Formal presentation, with discussion: Bioenergetics
13:40	14:00	Influence of warming temperatures on trout recruitment and size
14:00	14:30	Formal presentation, with discussion: Zuni perspectives
14:30	14:45	Break
14:45	15:15	Stakeholder Perspectives (Colorado River Energy Distributors Association)
15:15	15:45	Formal presentation and discussion: Little Colorado River HBC
15:45	16:35	Formal presentation and discussion: Humpback chub population dynamics
16:35	17:00	Recap, discussion
Thursday, August 04, 2016		
8:00	8:30	Formal presentation and discussion: Trout/chub interactions
8:30	9:00	Formal presentation and discussion: HBC aggregations
9:00	9:30	Formal presentation and discussion: Chute Falls Translocation
9:30	10:00	Arizona Game and Fish system-wide fish monitoring
10:00	10:45	Discussion: nonnative fish detection, monitoring HBC populations on lower river
10:45	11:00	Break
11:00	12:00	Questions from panelists to scientists and discussion
12:00	12:30	Final (review/summary) discussion
12:30	13:30	Lunch and break time at GCMRC
13:30	17:00	Panel meets in closed session at GCMRC,

Appendix C. Questions and issues provided to the PEP by the angler stakeholders August 2, 2016

1. Approaches to identify the root cause(s) of the unstable trout populations in Lees Ferry;

2. The highest priority actions to stabilize and enhance the quality of the aquatic food base and the Lees Ferry trout fishery;

3. The appropriate metrics to trigger TMF's, stocking, and other management actions;

4. The most appropriate methods and level of effort to effectively monitor progress towards achieving the goals outlined in the Lees Ferry Recreational Trout Fishery Management Recommendations, August 2015;

5. Important data gaps that need to be filled and uncertainties that need to be resolved; and

6. The need to develop or refine an existing Stock Assessment Model to:

    a. measure progress towards reaching the goals contained in the Lees Ferry Recreational Trout Fishery Management Recommendations, August 2015,
    b. determine the suitability of the metrics identified in the Recommendations, and
    c. evaluate the effectiveness of increasing harvest as a tool for managing the trout fishery.

7. A method or strategy for characterizing the overall health of the aquatic ecosystem including aquatic food base, native and nonnative fish, water quality and habitat quality/availability.

Appendix C. Questions and issues provided to the PEP by the Colorado River Energy Distributors Association, August 3, 2016.

The following are issues and questions for the panel meant to stimulate discussion. My work for the Colorado River Energy Distributors Association provides them with an environmental perspective on research and monitoring efforts in the AMP as they pertain to influences on dam operations. The following is a very brief list of what constitutes a very large topic. (My thoughts follow in parentheses.)

- The impacts of the Modified Low Fluctuating Flow operating regime on HBC survival, growth and reproduction are contained in a variety of research and monitoring efforts and reports, including those in the Near Shore Ecology studies by Pine and Finch.

The NSE study appears to conclude that the Grand Canyon population of young HBC is doing quite well utilizing a variety of available near shore habitats under a wide range of flow conditions. **Will the PEP be attempting to reach a conclusion after reviewing this material as to its comprehensiveness and quality and whether more research and monitoring should be prioritized to determine flow impacts on growth and survival? And if so, what types of research and monitoring**?

> (My hypothesis about HBC relation to river flows consists of having little worry. The research and monitoring could continue to dig deeper into their relationships; however, for purposes of developing recommendations on dam operations, the data are pretty conclusive that river flows have little effect on their growth and survival. River temperatures do have effects on growth and probably on their survival at the early stages as cold temperature does make them more susceptible to predation.)

- Actions needed to prevent future green sunfish (and other nonnatives) infestations,

Last year, a population of green sunfish was discovered in a backwater downstream of the dam. Great concern was expressed about allowing this population of aggressive, predatory fish to persist and eradicating this population was believed to be a necessary step; therefore, an eradication project was implemented using rotenone. Future influx of warm water nonnative fish from Lake Powell would appear to be a significant possibility. **Can the PEP offer opinions on the necessity for monitoring detection of entrainment, ideas on an adequate monitoring program to detect future fish entrainment from Lake Powell, what habitats downstream to monitor for their presence and point to research ongoing or planned on future preventative measures?**

> (My thought on this is to pursue physical modifications of the present backwater used by the GSF to create a flow-through system. This will move the fish downstream to Lake Mead, an existing habitat already used by GSF. There are other backwaters that GSF could hang in which could be similarly modified; but these may be sufficiently few and of small consequence to make much difference. Also, I think we could implement some more intense monitoring downstream of the dam to provide early detection of nonnative warm water fish coming through the dam. Smallmouth bass are the biggest concern.)

- Research on the value of temperature control and oxygen maintenance using dam bypass tubes

Bypass tubes on Glen Canyon Dam and many other dams exist at a lower elevation than the hydropower intakes. **Does the PEP see advantages to pursuing research efforts to determine the efficacy of their**

use to ameliorate temperature and oxygen conditions downstream of dams? If so, can the PEP offer some research approaches to establishing their efficacy?

(We would like to see if there are advantages to fish populations by use of the bypass tubes since their use for other purposes are many. If we can establish a collective benefit to fish and these other uses, perhaps this will be sufficient to justify their use.)

- Importance of establishing HBC origins in lower canyon.

Recent fish monitoring in the lower Grand Canyon have detected various life stages of humpback chub. It is currently unknown where these fish originate but there is much speculation. We think knowing their origin is important to future efforts to increase alternative habitat use and thereby secure the population against catastrophic losses. **Does the PEP think some research and monitoring approaches should be employed to help us determine their origins and if so, what ideas do they suggest short of actually sacrificing individuals?**

(The lower canyon is the location where humpback chub were originally identified but we do not know their numbers or origins. We believe some today originate within Havasu Creek and possibly one or more main stem spawning group. If we can identify their origins, there may be a way to enhance those populations. This enhances the overall canyon population and can further justify down- or delisting the species.)

- The rainbow trout population in the Colorado River below the dam has fluctuated widely over the last 10 years at least an order of magnitude.

Over the last few years, the food base for the trout population has morphed from one consisting primarily of Gammarus to one consisting more of black flies and midges. During the 3 decades following dam closure, Gammarus populations were high and persisted under high fluctuating flows, providing an abundant food base both within the Lees Ferry reach and downstream as drift. 1) **Does the PEP have any ideas on how we could approach obtaining answers to why this has occurred and its ramifications to the ongoing food supply for trout and downstream fish populations (e.g., HBC). 2) Does the PEP have any ideas on what linkage there may or may not be between fall HFEs and foodbase impacts compared to spring HFEs and foodbase impacts? What would be the most effective monitoring protocols to determine whether there are linkages?**

(Some believe that High Flow Experiments coincide with the change in Gammarus domination. There is some evidence that the recurring scouring during HFEs does not allow sufficient time for their recovery. Since the drop in their numbers coincides with the advent of HFEs, there is at least a high suspicion. Also, conducting spring HFEs, immediately prior to the growing season may have less impact on the food base than one conducted in the fall, prior to winter. There have been a preponderance of fall HFEs.)

- The value of using other trout strains to enhance the fishery.

There are hundreds of strains of rainbow trout developed over the last 150 + years, each with a different set of tolerances, capabilities, behaviors, etc. We see the Lees Ferry trout population as dominated by the Bel Aire strain, primarily due to it being a good hatchery product and are concerned that this may be attempting to put a “square peg in a round hole.” This strain may not be appropriately suited to the conditions prevailing below Glen Canyon Dam yet we continue to try modifying conditions to suit this strain. **Is the PEP aware of any efforts to marry trout strains to river conditions and if so, consider reviewing the suitability of various trout strains to be a worthwhile research topic?**

> (I have conducted two such studies and have managed to locate strains that may be better in tune with the type of fishery demanded by Lees Ferry anglers and the riverine conditions below the dam. The Bel Aire strain is not known for having the capability to reach a large size but it is easier to catch than others! Both studies are on file with GCMRC. I would like to know if others have attempted to marry strains with dam tailwater conditions or if this is even a worthwhile research topic given other priorities.)

Appendix I Acronyms

ADMB – AD model-builder software

AGFD – Arizona Game and Fish Dept.

CMIN – Core Monitoring Information Needs

CRe or CRE – Colorado River Ecosystem

FNU - Formazin Nephelometric Units

GCDAMP - Glen Canyon Adaptive Management Program

HBC – Humpback Chub

HFE – High Flow Experiment

JCM – Juvenile Chub Monitoring

JS – Jolly Seber model

LCR – Little Colorado River

LTEMP – Glen Canyon Dam Long-Term Experimental and Management Plan

MLFF – modified low fluctuating flows

MUX - Multiplexer

NEI – Net Energy Intake

NO – Natal Origins

NSFS – Nonnative fish suppression flows

PIT - Passive Integrated Transponder

PBR – Paria River to Badger Rapid

PEP – Protocols Evaluation Panel

RBT – Rainbow Trout

RD- Robust Design

RIN – Research Information Needs

RTELSS – Rainbow Trout Early Life Stage Survey

SSQs – Strategic Science Questions

TCD - Temperature Control Device

TMF – Trout Management Flows