Report to the Adaptive Management Work Group, Glen Canyon Dam Adaptive Management Program

An Independent Review of Ongoing and Proposed Scientific Methods to Assess the Status & Trends of the Grand Canyon Population of the Humpback Chub (*Gila cypha*)

Report of a Workshop Conducted During 6-7 November 2003 at the National Center for Ecological Analysis and Synthesis, Santa Barbara, California

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Report Contents:

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Executive Summary

In response to controversy over the methods employed in estimating abundance of endangered humpback chub (Gila cypha) in the Colorado River, the Adaptive Management Work Group of the Glen Canyon Dam Adaptive Management Program (GCDAMP) authorized Grand Canyon Monitoring and Research Center (GCMRC) staff to convene a workshop in review of the alternative methods currently employed. At present, there are six populations of humpback chub in the Colorado River Basin. The Grand Canyon population plus five discrete populations identified in the Upper Basin as distributed in each of three rivers; one in the Yampa River, one in the Green River and three in the upper reaches of the Colorado River above Lake Powell. Mark-recapture methods of population estimation have been employed in the Grand Canyon since the 1980's. Similar work began more recently in the Upper Basin sites.

The central controversy surrounds assumptions and methods of data analysis. Two approaches are employed. Closed population approaches, such as those employed in Upper Basin studies, are based on the assumption that all members of the population are vulnerable to sampling and that no animals leave or enter the population between sampling occasions. However, these models do allow relaxation of the assumption that all animals are equally vulnerable to capture on a given sampling occasion. Open population approaches, such as the Age-Structured Mark-Recapture (ASMR) model employed by GCMRC studies, assume that the population size can change over time due to mortality/emigration or recruitment/immigration. Vulnerability to capture can differ among sampling occasions, and age of fish can also influence vulnerability. However, open population models assume that all fish of a given age class are equally vulnerable to capture on a given sampling occasion. These differences in assumptions are critical. They evoke alternative approaches to data analysis that are central to the basic questions of population abundance, trend in abundance and recruitment.

A member of the GCDAMP Science Advisory Board, James Kitchell, was asked to organize this review by developing a Panel of Independent Reviewers to meet with representatives of the ongoing programs in the Grand Canyon and the Upper Basin. During the period of 6-7 November 2003, this meeting was convened at the National Center for Ecological Analysis and Synthesis in Santa Barbara, California.

Members of the Independent Panel were chosen because of their experience and expertise in fish population estimation. The Panel included Churchill Grimes and Steve Lindley of the National Marine Fisheries Service Laboratory in Santa Cruz CA. Both were selected because of their extensive experience in working with analogous issues for endangered salmon stocks. Other members included Carl Schwarz, Simon Fraser University, and David Otis, Iowa State University. Both are well-known biometricians specializing in the development of models used in analysis of population data. Prior to the meeting, all members of the Panel were provided with background material describing current practices by GCMRC and Upper Basin programs.

The Scope of Work (Appendix I) guided our focus. The Agenda (Appendix II) outlines presentations by representatives of the GCMRC staff and the Upper Basin. Tom Czapla forwarded a power point presentation as part of his participation by conference call. Discussion participants and observers included James Rice and William Pine of North Carolina State University. Both are authors of an extensive review of fish population estimation methods that appeared in a recent issue of the American Fisheries Society journal, *Fisheries* (Pine et al. 2003). Also among the observers were Steve Gloss, GCMRC, and Randy Peterson, Bureau of

Reclamation. Conference calls provided input by Tom Czapla, USFWS, and Chuck McAda, USFWS. The Panel's review is explicitly detailed in the Technical Assessments (Appendix III).

As an overview, the five charges presented in the Scope of Work and the Panel's findings are paraphrased in the following.

1. ***Are methods used in the Grand Canyon appropriate for determining status and trends of the humpback chub population there?***

The ASMR model is a variant of well-established and proven approaches. Its purpose is to reduce the bias in abundance estimates by accounting for changes in both juvenile and adult vulnerabilities to capture as adults move into or out of the LCR, and to utilize information on survival from previous tagging in estimation of capture probabilities for each year. The ASMR method accounts for those dynamics, but can be improved to remove potential biases due to additional sources of variation in capture probabilities.

2. ***Are Upper Basin methods appropriate for use in the Grand Canyon?***

The ASMR is most appropriate for the Grand Canyon work because it takes advantage of spawning aggregations in the LCR and efficiently uses the extensive data collected over a longer period of sampling there. Work in the Upper Basin is limited by the shorter time series, less extensive sampling, and the consequent constraint on providing estimates of recruitment, mortality rates, and/or trend in abundance. As more data become available in the Upper Basin studies, more complex models such as the ASMR can be applied. Upper Basin methods should not replace those currently employed in the Grand Canyon. There is no compelling scientific reason to change the basic spring sampling schedule for Grand Canyon/LCR work to a fall schedule. Doing so might create more problems than solutions.

3. ***Are there ways to improve methods used in the Grand Canyon work?***

The Panel encourages consideration of telemetry approaches to address questions about migration to and from the LCR, use of simulation studies to evaluate potential biases in ASMR population estimates, and recommends that results from well-established open population age-structured methods (Jolly-Seber models) be compared to results from the ASMR models. Similar analyses of Upper Basin closed model methods will also be informative.

4. ***Do Grand Canyon methods provide rigorous data pertinent to HBC Recovery Goals?***

The ASMR method is appropriate for getting estimates of abundance, population growth rate (i.e., trend), and recruitment, if assumptions about capture probabilities are reasonable. Upper Basin methods do not provide as much information about these three criteria because of much lower capture rates. In both cases, the Panel recommends that emphasis be placed on estimates of population growth rate in determining if a population is to be down-listed or de-listed.

5. ***Are the current methods providing scientifically rigorous data to inform decisions of the Glen Canyon Adaptive Management Program's Adaptive Management Work Group?***

Yes. Given the current constraints to work in Grand Canyon, the Panel views the basic structure of the ASMR model as the appropriate approach. Several potential enhancements in the approach should be pursued.

Conclusions and Recommendations

1. The analytical methods currently employed in the Upper Basin are appropriate *pro tem*, but could be improved as more data become available. The Panel encourages development of open population methods as the database improves and recommends development of simulation studies as a way to evaluate alternatives. In combination, those could help develop the "robust" approach advocated by many experts in population biology (Pollock 1982).

2. The Panel finds little merit in changing current sampling practices. Sampling should occur when the greatest number of fish can be captured with the least harm to the fish – i.e. spring in the Grand Canyon and fall in the Upper Basin.

3. The ASMR model proposed and applied by Walters and Coggins (2003b) is an appropriate way to deal with the biases introduced by heterogeneity in catchability related to age. It is based on the existing and proven methodology of Pollock (1981) and offers "best available science" as the source of evidence regarding the status and trends of humpback chub in the Grand Canyon ecosystem. The ASMR method can be improved and the Panel offers recommendations specific to future work in the Grand Canyon. Those are:

(a) Further work needs to be done on the extent of potential bias caused by inaccurate aging at initial capture.

(b) Use the Pollock (1981) Jolly-Seber age model directly to compare the estimates to the computer program developed by Walters and Coggins as a way to cross-validate that the method has been implemented correctly.

(c) Use the Pradel (1996) approach to estimating population growth (ignoring age classes) to cross-validate estimates of population growth/decline.

(d) Age-structured models assume that there is no further heterogeneity in catchability other than that due to age. Further work (e.g. some simulation experiments) needs to done to assess the potential degree of bias in parameter estimates that could result from additional sources of unequal capture probability. Those might be due to behaviors such as skip spawning, avoidance of sampling gear after first capture, or movement to/from the main stem.

4. The Panel encourages development of a workshop where Upper Basin and GCMRC program participants can bring their data sets, work with alternative modeling approaches and evaluate estimation methods. This would allow sharing of expertise, discussion of differences among sites, and help build consensus about criteria for de-listing or down-listing.

Appendix I: Scope of Work

Scope of Work

An Independent Review of Ongoing and Proposed Scientific Methods to Assess the Status & Trends of the Grand Canyon Population of the Humpback Chub (*Gila cypha*)

Background: The federally endangered Humpback Chub, *Gila cypha*, particularly the Grand Canyon population, has been a topic of considerable interest in recent months for the Glen Canyon Dam Adaptive Management Program (GCDAMP). This interest has resulted in part from the newly developed Recovery Goals for the species (issued in 2002), which contain criteria for down-listing and de-listing. Determinations of whether these criteria are met presumably will be based upon status and trend numbers using methods described in a draft Fish and Wildlife Service guidance document (March, 2002). The Grand Canyon Monitoring and Research Center (GCMRC), which acts as the research and monitoring arm of the GCDAMP, has been developing and following procedures somewhat different than those in the guidance document in studying the status and trends of the Grand Canyon population of HBC. These stock assessment procedures have documented a substantial decline in recruitment and adult abundance over the past decade or so.

The decline in numbers and recruitment in this population led the Adaptive Management Work Group (the FACA committee that makes recommendations to the Secretary of the Interior as part of the GCDAMP) to form a HBC Ad Hoc Committee in January, 2003 charged with developing a comprehensive action plan for improving the status of HBC in Grand Canyon. One of the projects developed by this group was an experimental implementation of simultaneous stock assessment sampling and modeling for the HBC population coupled with a two year implementation of procedures similar to those suggested by the population estimation guidance document for the recovery goals. However, implementation of this project in 2004 has been hampered by controversy over the seasonality, location, and intensity of sampling, as well as differences of opinion regarding the stock assessment procedures vs. closed population estimation procedures. These differences led the HBC Ad Hoc to recommend an evaluation of the merits of these various approaches by an independent review panel to be convened by the Science Advisory Board for the AMWG. This recommendation was concurred with by the AMWG's Technical Work Group and approved as part of TWG's FY04 budget recommendation to the AMWG. On August 14th, 2003 the AMWG approved the FY04 budget, which includes the evaluation of the different methods by the SAB and an independent panel of the SAB's choosing. This panel and the SAB are to report their findings to the AMWG by their January 7-8, 2004 meeting to enable the appropriate field sampling aspect of this project, as approved by the AMWG, to be implemented in the 2004 field season.

GCMRC, in meeting its responsibility to the AMWG, TWG, and HBC Ad Hoc Committee, is describing herein the scope of work and timetable for the independent review panel.

Purpose: Through an independent peer review process, determine the relative merits of population estimation and stock assessment procedures, or some combination thereof, being used by the GCDAMP and those being recommended by the Recovery Goal process for estimating the status and trends of the population of HBC in Grand Canyon.

Charge: Provide substantive written guidance to the GCDAMP AMWG sufficient to inform a policy recommendation regarding the implementation of population status and trend estimation procedures for the HBC population in Grand Canyon based upon the best available and practicable scientific methods. A report containing this guidance shall be submitted to GCMRC for transmittal to the AMWG no later than December 5, 2003.

Process: The SAB (acting through Dr. James Kitchell, the Hasler Professor of Zoology and Director of the Center for Limnology at the University of Wisconsin) shall convene a panel of independent scientific experts with background and qualifications in the areas of population dynamics, statistics, population estimation techniques, and stock assessment procedures as they pertain to fishery resources. This panel shall gather relevant information through written documents and in person presentations of information relative to the issue described under background above and develop a written report to the Adaptive Management Work Group of the GCDAMP. Based on their acquired knowledge of the HBC populations in the Colorado River Basin (and particularly Grand Canyon) as well as the field sampling and statistical methods being used to evaluate the status and trends of those populations, the panel shall produce a report which addresses:

1. Recommendations regarding the appropriateness of methods used in the Grand Canyon to develop status and trend information for the Grand Canyon and Little Colorado River populations of HBC.

2. Recommendations regarding the appropriateness of methods being recommended for use in the Upper Basin HBC populations and their transferability/utility in regards to the status and trends of the Grand Canyon HBC population.

3. Opportunities for using any combination of the different methods in the Grand Canyon, including considerations regarding the seasonality, sampling gear, and intensity of sampling.

4. The appropriateness of the various methods and approaches in providing scientifically rigorous data to inform the Recovery Goal process in determining whether or not down-listing and de-listing criteria have been met.

5. The appropriateness of the various methods and approaches in providing scientifically rigorous data to inform decisions of the Glen Canyon Adaptive Management Program's Adaptive Management Work Group.

Appendix II: Agenda

An Independent Review of Ongoing and Proposed Scientific Methods to Assess the Status & Trends of the Grand Canyon Population of the Humpback Chub (*Gila cypha*)

Meeting Agenda

November 6-7, 2003
National Center for Ecological Analysis & Synthesis
Santa Barbara, CA

Thursday, November 6

8:30am- Welcome and Introductions, ***Jim Kitchell,*** University of Wisconsin and Science Advisory Board, Glen Canyon Adaptive Management Program

8:45am- Review of Agenda and Scope of Work for Independent Review Panel, ***Kitchell***

9:00am- Overview of Humpback Chub Recovery Goals, Criteria for Down-listing & De-listing. ***Tom Czapla,*** Upper Colorado Endangered Fish Recovery Program, FWS (by conference call)

9:45am- Ecology, Distribution, and Sampling Methods for Grand Canyon Population of Humpback Chub***, Lew Coggins,*** Grand Canyon Monitoring and Research Center, USGS

10:30am- Ecology, Distribution, and Sampling Methods for Upper Basin Humpback Chub Populations, ***Tom Chart,*** Bureau of Reclamation, Salt Lake City; ***Chuck McAda***, Grand Junction, CO, FWS, (by conference call), and ***Doug Osmundson***, Grand Junction, CO, FWS

11:00am Statistical and Modeling Methods to Determine Status and Trends of Humpback Chub in Grand Canyon. ***Carl Walters***, University of British Columbia.

11:45am Statistical and Modeling Methods to Determine Status and Trends of Humpback Chub in the Upper Basin. ***Kevin Bestgen***, Colorado State University.

12:30pm LUNCH

2:00pm Open discussion, questions and answers from panel members

3:45pm Final Q & A from panel, requests for information.

5:00pm Adjourn

Friday, November 7 (Closed meeting of review panel)

8:30am-Preliminary discussions & reflections

10:30am-Draft Report Outline

12:00pm LUNCH

1:30pm- Writing of draft material

5:00pm adjourn

Panel Members:

James Kitchell (Chair), Center for Limnology, Univ. of Wisconsin
Churchill Grimes, Southwest Fisheries Science Center, NMFS, Santa Cruz, CA
Steve Lindley, Southwest Fisheries Science Center, NMFS, Santa Cruz, CA
David Otis, Cooperative Fish & Wildlife Research Unit, Iowa State University
Carl Schwarz, Dept. of Statistics & Actuarial Science, Simon Fraser University

Observers and Discussion Participants (day one)

Steve Gloss, USGS SBSC
Randall Peterson, Bureau of Reclamation
Bill Pine, Dept. of Zoology, North Carolina State Univ.
Jim Rice, Dept. of Zoology, North Carolina State Univ.

Appendix III: Technical Assessment

I. Mark-recapture models

A. Closed models used in the Upper Basin

The closed population model analysis used in the Upper Basin is an appropriate approach for producing independent population estimates in a given time and year. This method attempts to correct for potential biases in traditional population estimators that occurs when capture probabilities vary among individuals (heterogeneity) or vary due to a behavioral response to first capture, e.g., capture avoidance. However, these methods are not especially powerful in detecting variation in capture probability when the number of trapping occasions (passes) is small (<5), and average capture probabilities are low (<0.10). Unfortunately, both of these criteria pertain to the current Upper Basin situation. Thus, it is not surprising that population estimates produced to date by the computer program CAPTURE have poor precision and vary considerably among models.

Although we expect considerable stochasticity in capture probabilities due to unplanned environmental and logistical events, computer simulation of the performance of the methods under a variety of capture probability and population size scenarios is a valuable tool for assessment of expected outcomes of a proposed sampling protocol. In particular, we suggest that it would be a valuable exercise to simulate the bias and precision of the closed population models under each of a set of hypothetical range of values of the number of sampling occasions, expected population size, and capture probability structures. The results could be evaluated within the context of the population abundance recovery goal. For example, if we constructed a hypothetical population of N = 2,100 individuals, with reasonable values of expected capture probabilities based on past data, and simulated the results of a capture-recapture experiment based on three capture occasions within a short time frame, what would the resulting distribution of estimates look like with respect to bias and precision? Said another way, what are the chances that we would conclude that the population was significantly larger or smaller than N = 2,100? Such an exercise would explicitly inform stakeholders about the sensitivity and uncertainty in the proposed protocol, and allow an evaluation of alternative protocols.

We also suggest that the practice of treating data from each year of sampling as independent for previous or subsequent years is not the most efficient use of all of the available data (see next subsection).

With respect to sampling of individual populations in the Upper Basin, we agree with the suggestion to combine the Black Rocks and Westwater populations into a single population, but recommend that population abundance estimates be generated from stratified models (e.g. Schwarz and Taylor, 1998) that acknowledge the possibility of movement between the two areas. The Yampa, Desolation, and Cataract Canyon populations are more problematic in that abundance and recapture rates are apparently too low to produce credible estimates from capture-recapture sampling. As alternatives to continuance of the current sampling protocol for these areas, we suggest that it would be more efficient to either: 1) make a single pass through the area each year and simply generate an index of abundance that could be used to estimate trends in abundance, or 2) sample these areas more intensively but periodically, e.g., every 3 years.

B. Open models--the age-structured mark-recapture (ASMR) model as developed for the Grand Canyon.

There is a wide range in the type of mark-recapture designs and analyses used to estimate the important population parameters of abundance, survival, recruitment, and population growth when fish receive unique tags (see review by Pine et al. 2003). The very simplest design assumes a closed population (no death, no emigration, no recruitment, and no immigration) and takes a series of samples of the population. At each sampling occasion, the tag number of recovered fish is recorded and untagged fish are tagged and released. This is the basic protocol used for the Upper Basin populations. Because the population size is assumed as fixed, this is the only parameter that is of interest. A key assumption of these closed population models is that all fish have the same probability of capture at each sampling occasion (but this probability is allowed to change among sampling occasions). If this assumption of homogeneous capture probability is violated (e.g. some fish are more likely to be captured than other fish due to size, sex or behavior), then estimates of population size can be biased (i.e. tending to be too high or too low). The direction of bias depends on how the heterogeneity among fish changes over time. For example, fish that have a higher probability of capture at one occasion also have a higher probability of capture at another occasion (a "trap happy" behavioral response). In this case, the estimates of abundance have a negative bias (i.e. produce evidence of a smaller population than is the actual case). Alternatively, a fish may have a traumatic experience after being captured at one occasion and is less likely to be captured in subsequent occasions ("trap shy"). In these cases, estimates of abundance have a positive bias (i.e., overestimate the actual population abundance.

Several closed-population estimators have been developed for designs with three or more sampling occasions. Among those are the models M_0, M_t, M_h, and M_b, as summarized by Otis et al (1978), and implemented in the computer program CAPTURE. These models test for the presence of capture heterogeneity due to factors such as fish size, behavior or time effects and compute estimates of abundance that account for these effects.

Once multi-year studies are considered, the assumption of population closure is no longer tenable – some fish die and some fish recruit to the population. More complex capture-recapture models have been developed for these multi-year studies. They are generally known as Jolly-Seber models (Jolly 1965; Seber 1965). In these models, a capture history for each individually tagged fish is kept (the sequence of 0's and 1's indicating if a fish was not seen/seen in a particular year). From these capture histories, estimates of population abundance, year-to-year survival rates, and recruitment to the population can be developed. However, even for these multi-year models, a key assumption is homogeneous capture-probability among fish alive in a particular year, i.e. all the fish alive in a year should have the same probability of capture, although this probability can vary over years. In much the same way as in closed population models, simple heterogeneity (e.g. "trap happy" fish) leads to negative biases in abundance estimates while changing heterogeneity (e.g. "trap shy" fish) usually leads to positive biases in abundances.

Walters and Coggins (2003a) examined catchability of pit-tagged fish in relationship to time of year and age of the fish. They found that older fish have a lower capture probability than younger fish for many months of the year . The decline in catchability is most apparent when compared to sub-adult fish, but still could vary by about a factor of 2 between fish of age 5 and 15 years (their Figure 3). Similarly, there was some evidence that during the spring, older fish are more catchable than younger fish (their Figure 4). In both cases, these are examples of simple heterogeneity likely related to the age of the fish. Mark-recapture models that simply "pooled" over all age groups would be expected to produce estimates with a negative bias. This is probably the reason for the apparent bias in estimates from the SuperTag model that produces abundance estimates substantially lower than those derived from the ASMR.

Because of the complexity of these multi-year designs, models to adjust for heterogeneity are not as well developed as for the closed population cases (but see Pledger and Effort, 1998). However, if the sole source of heterogeneity is related to age, then Pollock (1981) developed a model (the Jolly-Seber age model) where the population is divided into several age classes. Capture (and survival) rates are allowed to vary among the age classes and over years, but are again assumed to be equal for all animals within a particular age class and a particular year. Because aging is a deterministic process (i.e. animals age by exactly one year each year), the age class (and hence the capture-probability class) is known for all occasions even when the animal is not seen. Estimates can be obtained of abundance, survival, and recruitment for each class. If age class data are the only source of heterogeneity, then estimates of abundance are now unbiased which is unlike the pooled analysis based on collapsing data over all years.

Walters and Coggins (2003b) present the development of an age-structured model that is based on the same principles as the Jolly-Seber age model. The population is divided into individual year age classes and movement of fish among the age classes is deterministic. Each age class has an individual capture and survival probability. Age specific estimates of abundance are then obtained and summed to obtain estimates of the total abundance.

A large number of age classes requires a large number of parameter estimates for survival and catchability.. Walters and Coggins (2003b) also developed a model where age-specific survival is a function of length (the Lorenzen curve of their Figure 1). This improves the precision of abundance estimators because the number of parameters to be estimated is reduced from one for every age class to a total of only two—those describing the shape of the curve for all age classes.

Accurate estimation of the age class at first capture is a key data requirement for this model. Unfortunately, age determination is impossible without harming the fish, so initial age is assigned based on a fish length at initial capture. Walters and Coggins (2003b) investigated the potential biases that could be introduced by inaccurate age determination at initial capture. They found that estimates of recruitment (and abundance) could be negatively biased. This is not unexpected as errors in age assignment now introduce simple heterogeneity into the probability of capture at each apparent age class, which leads to negative biases. They report on a suggested alternative to assigning age based purely on length that appears to reduce biases in estimates of abundance.

Walters and Coggins (2003a, 2003b) indicate that an earlier model (SuperTag) produced very low estimates of abundance because of differential catchability of fish by age (simple heterogeneity) and because of movement between the spawning grounds and the main stem and/or "skip spawning" (i.e., mature adults do not spawn every year),. If skip spawning is prevalent, then estimates of abundance only refer to the spawning population in that year – not to the entire population of adults. If movement to/from the main stem is occurring, then this could lead to positive biases in abundance. As developed in the following, one of our recommendations encourages methods for estimating the non-spawning population in the main stem.

B. **Use of complex models**

The Panel found quite a dichotomy between the amount of data available, sampling designs and models used in the Upper Basin and in the Grand Canyon studies. The Upper Basin studies are characterized by only a few years of data with small number of recaptures. The lower basin study has many years of data with many recaptures. Consequently, the modeling that can be done differs considerably between the two locations. In the Upper Basin, estimation is limited by the data – there are only a few years of data and very few recaptures. Simple models that are robust to violations of assumptions should be used. However, the choice of model should not be a straightjacket – as more years of data become available, more complex models should be built for the Upper Basin studies based on experience gained from the GCMRC studies.

Complex multi-year sampling designs allow complex models that can account for non-closure (e.g. estimating survival and recruitment rates) and for heterogeneity in capture probabilities (e.g. age classes). This does not mean that the simpler models used in the Upper Basin studies should not be used as part of GCMRC analyses. Rather, differences between estimates from the closed population models used in the Upper Basin could be compared with those derived from similar analyses of GCMRC data. Thus, estimates from the more complex models applied to GCMRC data could provide some information on the potential size of biases in the Upper Basin estimates.

Modeling and estimation techniques currently exist that can integrate multi-year data into a common framework. This allows improvement of population abundance estimates in all years as data accumulates and permits estimation of additional vital rates such as annual survival rates. An especially valuable set of models in this regard is that associated with the “robust” design developed by Pollock (1982). This design assumes multi-year trapping periods, and within each year there is a set of closely spaced sampling occasions. The idea is to use closed population models in Program CAPTURE to estimate abundance within years, and open population models (Pollock et al. 1990) to estimate additional parameters such as recruitment, survival and population growth rate. Such a sampling protocol and associated analysis might be well suited to the Upper Basin as more intensive sampling is conducted in the immediate future.

II. HBC sampling issues

A. Simultaneous sampling in main stem and LCR

It has been suggested that simultaneous sampling be undertaken in the main stem concurrent with the sampling on the LCR. The primary reason for this proposal is to try and estimate the size of the “hidden population” – i.e. the skip spawners or those that have spawned and moved out of the spawning grounds to the main stem before or after the sampling effort.

While, in theory, this would seem to provide much useful information, the Panel understands that there are severe logistical difficulties in sampling the main stem caused by flows and the types of capture gear that can be used. Evidence presented in the review also supports the view that LCR sites should continue as the primary focus of sampling effort. As suggested below, there are alternative methods for estimating the dynamics of immigration-emigration from the LCR. Further, the Panel questions the sole emphasis on estimates of total abundance. In fact, estimates of the spawning population may be just as suitable because efforts to estimate the total population are plagued by logistic constraints and may introduce unknown bias. If estimates of population growth rates (i.e., trend in abundance) are sufficient to advise management decisions re. de-listing and down-listiing, then it may not be necessary to mount a program of substantial cost in order to get a questionable estimate of total abundance. The Panel's views on this issue are developed in greater detail in the following.

B. Spring vs. Fall sampling

It was suggested to the Panel that sampling times be similar for all HBC populations, and that fall is a more appropriate time to sample these fish because of concerns about capture stress, handling mortality, etc. However, the life history of the Upper Basin and Grand Canyon populations appear to differ because Grand Canyon fish exhibit annual, site-specific spawning migrations into the LCR. The Panel was not presented with any evidence of site-specific spawning migrations in the Upper Basin populations and assumes that these fish spawn within the reaches generally designated as habitat for each population. Choice of fall sampling in the Upper Basin sites appears to derive from a combination of constraints—high spring flows, high summer temperatures, and bycatch of other endangered species (e.g., Colorado pikeminnow). In combination, those make fall sampling the most appropriate choice.

Because of the long lifetime of these fish and the general restriction to abundance estimation for adults, there is no rationale for standardizing timing of the surveys to make abundance estimates comparable – i.e., the population size in the spring is likely very similar to the population size in the fall – well within the precision of any abundance estimate at either time point.

Ironically, even though the majority of the population in the Grand Canyon is in the main stem in the fall, the much lower capture rates in the main stem will lead to fewer fish being captured and to estimates with lower precision. Thus, requiring a fall sampling schedule for Grand Canyon work may produce more problems than solutions.

Consequently, **the Panel recommends that sampling occur when the greatest number of fish can be captured with the least harm to the fish** – i.e. spring in the Grand Canyon and fall in the Upper Basin.

III. Additional statistical issues

A. Model selection and model averaging

A common problem in statistical science revolves around choosing the most appropriate model for parameter estimation from among a set of proposed models. There is always uncertainty in this exercise, as the 'true' model can never be known. We can only hope to find a model that provides a good statistical fit to the observed data and one that has biological relevance to the problem at hand. Burnham and Anderson (1998) present a contemporary paradigm for model selection in the ecological sciences. This paradigm emphasizes achieving a parsimonious tradeoff between bias and precision of estimated parameters, i.e., models should be complicated enough to sufficiently explain the important sources of variation in the data, but be no more complicated than is necessary. The procedure involves *a priori* development of a set of biologically plausible models. The data are then used to assign an information theoretic quantitative score to each model, and this score can subsequently be used to rank the relative support for each of the models. For example, models that assume constant survival and/or capture rates can be objectively compared to alternative models that allow these rates to vary by age or time. It often happens that several models may be nearly equally supported by the data. In such situations it is possible to combine estimates from each of these models in a statistically optimum way. This produces model-averaged estimates that are statistically robust, allows for adjustment of violation of model distributional assumptions, and **explicitly acknowledges statistical uncertainty in the model selection process**. The ASMR methodology as currently applied does not involve a formal evaluation of the relative strength of support for alternative models. We suggest such an exercise be conducted with the Grand Canyon data as a way to compare results and evaluate robustness of model estimates. We note that model-averaging procedures can also be used on a limited basis with closed population models, although the statistical advantages are more limited.

B. Estimating population abundance vs. population growth

One of the criteria of the recovery plan relates to the absolute abundance of the population. Unfortunately, focusing upon absolute abundance as a measure of success/failure creates three important problems.

The first problem has to do with closure – to what geographical region does the estimate apply? Not all geographic areas can be sampled because of cost or logistical constraints, i.e. some stretches simply cannot be sampled. The Panel was presented with evidence of small number of chub outside the sampled areas in both the Upper Basin and Grand Canyon sites. Unless there is complete mixing of fish from the entire population with the fish in the sampled sites, any estimates of abundance can be negatively or positively biased. For example, if all marked fish moved to inaccessible sites and fish from inaccessible sites move to sampling sites, then no marked fish would be recaptured and abundance estimates will be strongly, positively biased. If fish in accessible and inaccessible sites never mixed, then the estimates will be very negatively biased. While the actual problems in field sampling are probably not this severe, the degree of mixing is neither well known nor accounted for in the analyses.

Second, mark-recapture estimates of abundance can be seriously biased by heterogeneity (see Pollock et al 1990; Link in press). While more sophisticated models can be developed to deal with certain types of heterogeneity (e.g. age related as in the ASMR), these are "data hungry" and require a long time series with high capture rates. Pradel (1996), Schwarz, (2001), Nichols and Hines (2002), Hines and Nichols (2002) demonstrate that population growth can be directly measured from mark-recapture studies. Estimates of population growth are much more robust to heterogeneity (Schwarz 2001; Hines and Nichols, 2002) under the much less restrictive assumption that the heterogeneity of the population doesn't dramatically change over time, i.e. older fish always tend to have higher capture rates. Estimates of population growth do not depend upon geographic closure as long as the growth/decline rates of the sampled population matches the population as a whole. Accordingly, **the Panel strongly recommends that population growth rates be given a higher priority than absolute abundance estimates** when evaluating the evidence for down-listing or de-listing**.**

Lastly, the recovery goals do not appear to incorporate uncertainty in the population estimate as part of the decision process. For example, if the recovery goal is 2000 fish, then an estimate of 2500 (se 400) fish provides a much different basis for decision-making than an estimate of 2200 (se 50) fish. The Panel recommends that, if absolute abundance is to be used, uncertainty in estimates be formally recognized in the review process, e.g., the lower bound of the 95% confidence interval for abundance be greater than some target value.

C. Analysis of power to detect population trend

The HBC recovery goals require estimation of population trend during specified time intervals to evaluate the objective of a stable adult population size. In statistical terms, the Panel assumes this means that the estimated population growth rate is not different from a value of 1. We encourage some **rigorous assessment of the statistical power** of proposed sampling designs and protocols to detect meaningful departures from a stable growth rate. Such an assessment could be accomplished by computer simulation studies that rely on informed assumptions and parameter estimates from existing data.

D. Technical expertise in model fitting

It is clear to the Panel that the Upper Basin and Grand Canyon programs are at different stages of development in terms of data collection and data analysis. Accordingly, we **recommend that a workshop be convened** where Upper Basin and GCMRC scientists can bring their data sets, work with alternative modeling approaches, and compare various estimation methods. This would allow sharing of expertise and discussion of differences among sites. This practice has been put to substantial benefit elsewhere such as among regions attempting to deal with Northern Spotted Owl issues.

IV. Responses to the Scope of Work

Brief responses to the Scope of Work charge are paraphrased and presented in the Executive Summary. In this section, the Panel responds in detail and specifically to each of the elements:

1. Recommendations regarding the appropriateness of methods used in the Grand Canyon to develop status and trend information for the Grand Canyon and Little Colorado River populations of HBC.

The proposed Age Structured Mark Recapture (ASMR) method is a variant of the established Jolly-Seber-Age model (Pollock 1981), and the Panel recommends that existing data be run with these standard mark-recapture models to obtain some cross validation on the results. If specific assumptions about the structure of capture probabilities are met, the method should produce unbiased and efficient estimates of annual survival, trend, recruitment, and absolute abundance. The method reduces bias of abundance estimates obtained from mark-recapture models caused by heterogeneity in catchability due to age. This flexibility is important for HBC population estimates, because there is evidence that older fish have different catchabilities than younger fish. However, the AMSR method may produce biased estimates of abundance if there is significant additional variation in capture probabilities within a year due to: 1) inherent differential catchability among individuals within age classes due to inaccurate aging or unequal exposure to capture, or 2) a behavioral response due to first capture, e.g., a change in movement or space use patterns that would reduce probability of subsequent recapture.

2. Recommendations regarding the appropriateness of methods being recommended for use in the Upper Basin HBC populations and their transferability/utility in regards to the status and trends of the Grand Canyon HBC population.

The method used in the Upper Basin population is limited to estimation of absolute abundance during a short time frame within a single year. For this purpose the method is accepted standard practice in closed population mark-recapture studies and offers the flexibility to handle problems with heterogeneity and behavioral response in capture probabilities (Otis et al. 1978). However, use of the method to date has resulted in estimates with relatively poor precision and uncertainty regarding the appropriate assumptions about the structure of the capture probabilities. We surmise that these results are due to the small number of sampling occasions within a year, the low capture probabilities that have been achieved, and the small number of recaptures obtained. The current number of sampling passes within a year is therefore likely too small in the Upper Basin and program to ensure reduction of potential biases caused by heterogeneity and other failures of assumptions.

The current Upper Basin method of using only the data from a given year to estimate abundance for that year is statistically inefficient for estimation of population trend and does not produce estimates of additional population vital rates such as survival, because it does not take advantage of available recapture information among years. Some improvement in trend estimation is possible using the three or more years of available data rather than concentrating on simply using the data from a single year. As additional years of data become available, more complex models should be fit that will efficiently use all of the data. The GCMRC program has a long time series of capture-recapture information that naturally lends itself to more complex models such as Jolly-Seber and ASMR methods for estimating survival rates and population trend, and these data should be fully utilized in analyses that may not be possible or as promising with existing data from the Upper Basin. In short, the Upper Basin methods are appropriate for the present, but could be improved by more expansive use of the existing data and as the data sets grow to allow analyses such as those employed by GCMRC.

3. Opportunities for using any combination of the different methods in the Grand Canyon, including considerations regarding the seasonality, sampling gear, and intensity of sampling.

There are no compelling scientific reasons to switch to a fall sampling schedule. The life history of the species is different in the Grand Canyon because there is substantial movement associated with spawning migration. Sampling is more difficult and capture probabilities are lower in the main stem, and therefore fall sampling may result in estimates with less precision than those from spring sampling because a greater proportion of the population will be less catchable in the fall. The Panel was unable to comment on sampling gear other to note that some radiotelemetry (or related methods) may provide valuable information on movements between the LCR and the main stem, as well as auxiliary information about capture probabilities. Use of this technology could answer some of questions about why some fish are not catchable because of skip spawning or early movement from the spawning grounds. The sampling intensity (number of passes/sampling occasions per year) is inadequate for highly reliable closed model adjustment of within year abundance estimates due to heterogeneity in capture probabilities, but intensity is probably sufficient for estimation of survival, recruitment and trend.

4. The appropriateness of the various methods and approaches in providing scientifically rigorous data to inform the Recovery Goal process in determining whether or not down-listing and de-listing criteria have been met.

Capture-recapture techniques are the most appropriate sampling method for producing estimates of population size, survival, trend, and recruitment that can be used in the Recovery Goal process. Goals based primarily on absolute population abundance renders the sampling and estimation problem much more difficult, because unbiased estimates of this parameter are the most difficult to produce from capture-recapture data. Increased intensity of sampling within years will be important for both programs if more reliable annual abundance estimates are required. An alternative plan is to conduct only a year or two of increased sampling in some areas to estimate the necessary capture probability structure and then use these estimates to calibrate future estimates from less intensive sampling. For estimates of trend and recruitment, multi-year models such as ASMR/Jolly-Seber are most efficient in using all available data, and should be utilized in both programs. The Panel cautions against thinking in terms of having to make a choice between one or the other of closed versus open population models. Instead, the monitoring program in both basins would benefit from utilizing well-developed robust model methods that integrate the best features of both closed and open capture-recapture models (Pollock 1982). In addition, we would strongly suggest the use of computer simulation exercises to investigate the potential biases in population estimates that might be expected from using current protocols. This approach would allow assessment of the statistical power of the current methods to detect change in population trend during specified time frames. That is, decision makers should be explicitly aware of the sensitivity of current methods to detect meaningful changes in the Recovery Goal parameters.

5. The appropriateness of the various methods and approaches in providing scientifically rigorous data to inform decisions of the Glen Canyon Adaptive Management Program's Adaptive Management Work Group.

As summarized throughout, the Panel feels that the current approach (ASMR) is clearly most appropriate within the logistical constraints of work in Grand Canyon and, therefore, the best currently available source of information for decision making. However, there is both need and potential for improving this basic approach. The Panel's review of the ASMR and alternative methods are presented above and include recommendations for improvement of methods employed in both the Upper Basin and Grand Canyon programs.

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Additional Documents Reviewed by the Panel

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Protocols for Colorado Pikeminnow and Humpback Chub Population Estimates. **Draft Report**, Program Director’s Office, Upper Colorado Endangered Fish Recovery Program, Lakewood, Colorado. 77p.

Grand Canyon Monitoring and Research Center. 2003. An Overview of Status and Trend Information for the Grand Canyon Population of the Humpback Chub, *Gila cypha.* Report to the Glen Canyon Dam Adaptive Management Work Group, Ad Hoc Committee on Humpback Chub. 23p.