Salmonid Integrated Life Cycle Models Workshop

Report of the Independent Workshop Panel

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Workshop Organized by the Delta Science Program

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1. Introduction

At the request of the National Marine Fisheries Service (NMFS), the Delta Science Program formed an independent review panel (Panel) and organized a public workshop on integrated life cycle models for salmonids in the Central Valley. The 2009 Biological Opinion (NMFS Opinion) on the Operations Criteria and Plan (OCAP) of the Central Valley Project and State Water Project describes the adverse impacts of water operations on the ESA-listed anadromous fish species (winter and spring Chinook salmon, steelhead, and green sturgeon). Included as part of the Biological Opinion (BO) process was specific actions (reasonable and prudent alternative, RPA) designed to mitigate those impacts. Life cycle modeling was not used for the 2009 OCAP BO.

NMFS recognizes the need to better integrate life cycle models into their assessments of the effects of water operations and RPA actions on the listed anadromous fish species. Peer reviews related to the NMFS Opinion (CALFED 2009; CVPIA Review 2008; NRC 2001) have all recommended increased usage by NMFS of life cycle modeling as part of the analyses in the BO and RPA actions. Also, recent court decisions have examined the validity of certain NMFS Opinion actions because they do not consider the whole life cycle of the protected species.

NMFS and the implementing agencies are interested in improving their understanding of existing life cycle models and obtaining recommendations on how to proceed with model development. The purpose of the workshop and the Panel was to provide recommendations to the NMFS on salmonid life cycle modeling for use in assessing water operations on listed salmon species and for evaluating the effectiveness of RPA actions.

2. Process

The Panel consisted of four members selected by the Delta Science Program: James Anderson (University of Washington), Michelle McClure (NOAA, Northwest Fisheries Science Center), Kenneth Rose (Louisiana State University), and Gregory Ruggerone (Natural Resources Consultants, Inc.). Dr. Rose was the chair of the Panel. CVs of the panel members are available from the Delta Science Program. Note that Drs. Anderson and Rose have been involved with several earlier review panels related to the OCAP BOs.

The Panel was provided with the documents listed in Appendix A as background material to read prior to the workshop. A conference call was held on March 22 with the Panel and Delta Science Program staff to explain the workshop objectives and format. The workshop took place on April 13 in Sacramento. Presentations were made by various model developers and users (Appendix B), and a discussion period followed that involved the panelists, presenters, and the public. The Panel met that evening and reached consensus on their major conclusions and recommendations. The final report was then prepared via email and conference calls. Several panel members also had the opportunity to discuss NMFS's general goals and plans about life cycle modeling with Dr. Steve Lindley while at other meetings. This report was approved by all panel members.

The workshop provided a forum for the Panel to hear about the various models and to also get a better understanding of the sense of the audience about life cycle modeling. Our recommendations reflect both the technical aspects of developing a life cycle model and the broader issues of communication to the general audience. During the workshop, it became apparent that the overarching question to the Panel was "How should NMFS proceed with development of a salmonid life cycle model for the Central Valley?" In addition to the questions in our charge, we used this opportunity to offer general advice and recommendations to answer this overarching question.

3. Charge

The Panel was asked to provide general recommendations on how NMFS should proceed with further incorporating life cycle modeling into their ongoing analyses related to the OCAP BO and RPA actions, and was charged with answering the following four specific questions:

1) Which model(s) are most appropriate for informing NMFS of the effects of water operations and prescribed RPA actions on salmonids at various life stages and at the population level?
    a) What are the strengths and weaknesses of the model(s)?
    b) What are key parameters and performance measures captured in the model(s)?
    c) How can this/these model(s) be applied to address the multiple timescales associated with RPA decisions and operations?
    d) What are the technical constraints to the implementation of the model(s) and the feasibility to address them (e.g. transparency of the model, data set(s) availability, model parameter uncertainties and sensitivities, etc)?
2) How can multiple specific models be linked to represent the whole life cycle to inform NMFS in determining the effects of water operations and prescribed RPA actions on salmonids at the population level?
3) How well can the models be adapted for species other than what the model was originally developed?
4) How can the models best fit into a decision-making framework for using life cycle models (at appropriate temporal and spatial scales) to adapt water operations and prescribed RPA actions on individual and multiple species?

The next section (section 4) summarizes the models presented at the workshop. The fifth section discusses the general recommendations of the Panel. This is followed by a sixth section with specific answers to the charge questions. We end with a concluding statement. There is overlap between the general recommendations and answers to the questions; general recommendations are therefore referenced in the answers. The general recommendations and answers to the specific questions are based on the presentations and discussions during the workshop, the panelists' experience with these particular and similar models, knowledge of the salmon issues in the Delta, and general experience with modeling fish population dynamics and population responses to changes in environmental conditions.

4. Overview of Workshop Models

The models reviewed at the workshop fall into three categories: (1) mechanistic models that define survival between life stages with specific mechanisms. In these models, the coefficients defining the vital rates are set by independent studies or by best guesses; (2) statistical models that define stage survival by weighing the contributions of a large number of habitat-specific time-varying environmental covariates to the overall stock recruitment pattern. These models infer no specific mechanisms but include or discard environmental covariates from the final model according to their statistical contributions to fitting the historical data; and (3) dynamic programming models that consider how growth and life stage transitions decisions optimize fitness over the life history.

Mechanistic models: The SALMOD, Shiraz models, and Interactive Object-oriented Simulation (IOS) are mechanistic models in which discrete life stages are defined. For example, a set of life stages could be: spawner, egg, fry, multiple smolt stages depending on rearing (river or Delta), and an ocean stage. Each stage has an entering abundance and, via a survival function, generates an exiting abundance. Typically, functions describe the movement of fish from one stage and habitat to another stage in another habitat.

Shiraz.—Shiraz uses a Beaverton-Holt mortality function in which stage survival depends on stage-specific relationships between environmental parameters (e.g., flow, temperature, sediment, riparian cover, road density) and survival. Each stage has a carrying capacity that adjusts density-dependent survival. Movement between stages can be defined in terms of an ideal free distribution based on relative survivals (i.e., fitness) between habitats, or fish can move from one spatial box to another through fixed movement fractions. Maturation and spawning are set by coefficients allowing multiple spawning schedules. By relating habitat actions to the survival variables, the model relates the actions to population dynamics. Measures are thus expressed in terms of percent increase in stage survival and carrying capacities. They can also be expressed as changes in full life-cycle survival or in projected abundance at the end of a specified time period. The model moves fish through each stage in a fixed manner that is set by the known properties of a particular run.

SALMOD.—SALMOD has a framework similar to the Shiraz framework but with notable differences. The SALMOD model combines information regarding run timing with finer-scale (up to daily) data regarding spatial and temporal variations in flow and temperature to define computational units. The units are then used to assess the effects of river flow and water temperatures on the production of salmon.

SALMOD is similar to Shiraz in defining how a cohort moves through various life stages and habitats. Fish abundance moving from one life stage to the next depends on survival which, in turn, depends on stage and habitat-specific environmental parameters. The model specifies up to three life history variants representing anadromous and freshwater species. This capability allows some representation of multi-year life history patterns of spring Chinook and fixed patterns like fall and winter Chinook and resident steelhead. The model allows further complexity within a life stage resulting in 15 classes within a life history strategy. Temperature is a major determinant of survival and habitat physical properties also affect survival via relationships between fish density and habitat-specific capacity measures. Growth is a function of temperature. Freshwater movement is fixed by freshet flows, when a fixed number of fish move or by a seasonally fixed movement. In both cases, the movement is specified by the model user.

IOS.—The Interactive Object-oriented Simulation (IOS) model is used for comparing the relative impact of different flow, temperature, and water export scenarios on the winter-run Chinook population. IOS is designed to compare the relative survival rates under alternative operations. The model takes the discrete life stage approach moving fish through stages, and routes fish through the Delta using the Delta Passage submodel that contains significant details on how the Delta is connected. As in the SALMOD model, the life stage transitions are provided by the user.

SLAM.— SLAM is a general simulator and so offers a variety of options for modeling stage-specific survival and demographic interactions between populations (or sub-components of a single population). It includes the ability to include a number of stock-recruitment functions (including Beverton-Holt), variability in all parameters, as well as a data fitting option. SLAM also uses the approach of covariates influencing survival rates from life stage to life stage, using functions that relate number of incoming individuals to the number that exit. SLAM is not a model per se, but rather a platform in which a model of almost any structure, within the options offered, can be developed.

Statistical model: OBAN is a statistical life cycle model that includes life stages based on a Beverton-Holt function. OBAN defines the transformation from one life stage to the next in terms of survival and carrying capacity. Unlike the mechanistic models, it does not consider the timing of movement between stages or habitats. Additionally, the survival and carrying capacity parameters are determined by a set of time varying covariates. There is no specific mechanistic relationship between the parameters and the survival and carrying capacity. The weighting terms for the influence of environmental covariates on the Beverton-Holt functions are established by fitting the model to spawner recruit data.

Dynamic programming model: The *s*tate-dependent life history (SLH) model presented at the workshop is based on a different framework than the other models reviewed. Instead of predicting survival under specified habitat conditions, SLH evaluates the fitness of alternative (steelhead) life history strategies. The model asks, given growth determined by environmental conditions, what choices between anadromy and residence provides the fittest life history strategy. The SLH model addresses: (1) whether strategies currently displayed are optimal; (2) should we expect evolutionary changes given the current conditions; and (3) what sort of evolutionary changes should we expect under future environmental conditions. Life stage decisions (smolts, mature, remain uncommitted) are determined by decision points based on growth trajectories prior to the decision. The model does not actually follow how fish make these decisions, but identifies which decisions provide optimum fitness. These strategies are then compared to observed strategies to determine if the fish are in fact using the best strategy. The solution technique is usually based on going from conditions now back into the past. Use of SLH for forward-looking projections involves the use of integral projection models.

Some Differences in the Reviewed Models

The models presented at the workshop address different questions. The SLH approach asks, given environmentally controlled growth, what is the best life history strategy? Mechanistic models (SALMOD, Shiraz, and IOS) track cohorts through space and time according to assumptions on survival and carrying capacity that are inferred from semi-mechanistic relationships to environmental parameters. These models attempt to predict how variations in environmental properties of the habitats affect the stage survivals and ultimately, population dynamics. The models can be used to predict how a population will respond to changes in the environment, under the assumption that none of the fundamental relationships between survival and the environmental variables will change. The statistical modeling approach (OBAN) identifies a possible set of environmental covariates that produced the historical pattern of population numbers. It can then predict future patterns of populations by altering the future pattern of relevant covariates; again, under the major assumption that the fitted relationships are stationary. SLAM is a general coding platform, rather than a model of specific species or system.

5. General Recommendations

Our general recommendations are grouped under the categories of: philosophical, communication, technical, and ownership. Many of these recommendations are known to model developers and users; we stated them here to provide a blueprint for future model development and for those readers who may not be familiar with the process of model building.

Philosophical

(1) Models should be developed and scaled for the questions to be addressed.

Developing a life cycle model involves judgment by the developers as to what to include in the model (and what to leave out), how best to simplify the processes (growth, mortality, reproduction, movement) to be included, and the time and space scales to explicitly represent. There is pressure to include complexity because everyone knows of details about the system that are important. Countering this pressure for complexity is the push back from the limitations imposed by the lack of available data and the general principle of parsimony. Data are needed to estimate model parameters and inputs, and to check model performance. This balancing among complexity, data, and parsimony is sometimes referred to as “the art of modeling.”

It is important to note that all modeling relies on a degree of judgment. People sometimes get the impression that life cycle population modeling is extreme in the need for judgment, with the model almost appearing arbitrary in its development. For example, hydrodynamics modeling appears to people as well-known and hydrodynamics model development as more rigorous. This perception arises from hydrodynamics modeling relying on known physical principles (conservation of mass and continuity of momentum). However, there is a large element of judgment and “art” to hydrodynamics modeling as well: resolution of the grid, type of grid, solution method, and turbulence closure terms. Thus, while life cycle modeling has a less rigorous foundation from which to build than hydrodynamics, all modeling involves judgment.

The most useful models are those developed to address a specific question. The question then guides the decisions and judgments made as to the detail needed, what can be greatly simplified or ignored, and the resolution (time and space scales) needed in the model. A danger is to develop a general model and then try to use it to answer specific questions, when a different model would have been developed if one started with the specific question. All models are approximations and thus model answers to specific questions are already inexact. Use of an overly general model for specific questions can make this situation worse by resulting in greater inaccuracy in model answers (i.e., above and beyond what a well-suited model would generate). One can end up in a situation of a single, general model that provides inadequate answers to all of the specific questions. At the other extreme, there cannot be a new model for each specific question.

In the situation of NMFS developing a salmon life cycle model, the issue of knowing the question is complicated. One set of questions that relate to the RPA, and its associated specific actions, are well known; the RPA actions tend to be specific and have been refined over time, as the BO and RPA undergo extensive review and scrutiny. This scrutiny and refinement tends to focus the details and expected effects of the RPA actions and results in synthesis and scrutiny of the available data involved, and actually greatly helps in model design, development, and scenario analysis.

However, several aspects can complicate the issue of knowing the questions, even in the situation of a well-reviewed BO and defined RPA actions. Even with well-defined questions now, questions will continue to evolve over time. At some point, the questions evolve to the point where the model becomes poorly scaled and must be modified to address the new version of the questions. Also, while the RPA actions may be known, there is the issue of whether there are better alternative RPA actions, which pushes the modeling into a very broad arena (i.e., the universe of what else could be done as RPA actions), and these alternatives have had much less scrutiny.

In addition, there may be situations in which a combination of models is most appropriate. For instance, a simple matrix model might be used to identify life stages with particularly strong influence on overall population productivity, or to quantify the general magnitude of change that is needed to achieve population viability from current conditions. Then, a mechanistic model or statistical approaches aimed at that life stage, might be used to evaluate particular suites of actions or combinations of conditions for their likelihood of attaining those goals.

(2) The resolution of the model results must be clearly stated.

There is often confusion among the audience about the proper interpretation of model results. Two important distinctions are prediction versus forecasting and relative versus absolute responses. We use prediction to mean model results under existing or new conditions, with forecasting associating specific years to the model results. Forecasting implies that the model results are what we would expected to observed in the field in that specific year. Thus, predictions are more general (some would say more vague) than forecasts. Relative responses mean that model results (e.g., number of fish) are only interpretable when compared to a modeling baseline, rather than to the number of fish observed in the field. Absolute results means the number of fish predicted by the model is the actual number expected to be observed in the field.

We recommend that when model results are presented, the appropriate level of interpretation must be clearly stated. While there is a continuum between prediction versus forecasting and between relative versus absolute results, it is easier to consider these as discrete categories for discussion purposes. Stating whether model results are predictions or forecasts and whether they are relative or absolute results is a good start towards proper interpretation. In addition, spatially-explicit results should also be put into the proper context. The confidence of spatial differences in model results should be described.

The objectives and power of the modeling should be clearly stated in order to manage expectations. Model results can appear to be too disconnected from reality to be useful to some people, while the same results can appear to be sufficiently accurate depictions of the future state of the system to other people. It is important to present model results with a clear discussion of the strengths and weaknesses. Some measure of uncertainty, which is not always possible, helps put modeling results into context. When presenting results with uncertainty, it is important to explain what sources of uncertainty are included in the outputs and which sources are not included. Uncertainty estimates will almost always be underestimates of the true uncertainty associated with modeling results. Also, there is confusion about uncertainty versus stochasticity. Uncertainty arises from ignorance and more data would reduce the uncertainty (e.g., relationship between temperature and mortality rate). Stochasticity is inherent variability (e.g., occurrence of a low flow year) that cannot be reduced with more information.

(3) The model should be designed from the ground-up, rather than trying to use an off the shelf model.

The Panel recommends that NMFS develop a model (or models) from the beginning. NMFS should use the existing models as guidance and the foundation, but should not try to modify one of the existing models to use for evaluating water management and the RPA actions. None of the models reviewed was completely appropriate alone for the needed life cycle model. Furthermore, none of the codes from the existing models, including SLAM, which is a general model, should be used for the NMFS model.

There are advantages and disadvantages to developing a new model versus modifying an existing model. Advantages to a new model are that NMFS decides each and every detail of the model, there is no confusion of which version of the existing model is being used, and NMFS will know every line of the code (i.e., minimizes inheritance of hidden assumptions or calculations). With a new model, there is no explanation needed as to why a particular existing model was selected to be modified over another. Also, all of the existing models evolve over time and so the point of reference changes and at some point, sufficient modification of an existing model really means you have a new model anyway.

Disadvantages to developing a new model are that more effort is involved with developing a new model and there is no historical context for the new model that would be available by modifying an existing model. The past performance of the existing model, available code, and that it has been tested previously (i.e., all of the equations fit together) are all benefits of using an existing model that are lost with a new model.

In the situation here, the Panel determined that the benefits of developing a new model (with the existing models as the foundation and proper documentation) outweighed the advantages of modifying an existing model. Modeling how CV salmonid species adapt to changing environmental conditions will require levels of modeling beyond those capable in the models reviewed by the Panel. In particular, to understand response of species over evolutionary scales, which may be as short as a few decades, a model must deal with the inherent heterogeneity in fish physiology and life history strategies. Indeed, the complexity of migration timings and size of fish found in the Central Valley are strongly suggestive that strategies are complex, varied, and under constant selection. Models that consider only single cohorts and overly fixed-in-space life-stages are simply inadequate to project the impact of future environmental changes on Central Valley salmon. In fact, we suggest the pertinent question is not about adapting one of the existing models to different species. The relevant question is how physiological and behavioral heterogeneity within a population can be incorporated into a framework so as to model the effects of environmental changes on population fitness and extirpation of Central Valley salmon runs. The frameworks of mechanistic and statistical models reviewed do not appear to be suitable to address such questions. The SLH model begins to address the issue; however, it was designed to address life history fitness alone, not population level changes. Such issues are not insurmountable. NMFS will likely need to look beyond the CV and the models presented at the workshop for possible approaches (e.g., Zabel et al. 2006; Li and Anderson 2009[1]).

Communication

(4) A standard glossary should be prepared and updated periodically.

We urge that NMFS keep an ongoing glossary of terms and definitions related to the life cycle modeling. Modeling often involves terminology and jargon that is unknown to the general audience and has different meanings to different people. Terms such as: model, code, solution technique, calibration, validation, scenario, and other terms, should be defined specific to the life cycle model being developed. There is enough to discuss about the model and modeling results without also having to repeatedly get through the confusion created by terminology.

(5) Presentations and written documentation should be prepared and tailored to the audience.

Effective communication of how the model works and interpretation of the results is critical. The presentations at the workshop, while each was well done and self-contained, illustrated the potential problems with trying to present a complicated model and results in a presentation to a general audience. Each model was described differently, even though they shared being life cycle models of salmonids. There was clearly confusion among audience members and panel members about the differences and similarities among the existing models. It would be difficult to compare across models (e.g., how is migration represented) based on the presentations and the documentation of the models. Part of this confusion was due to differences in style of the presentations, limited time allocated to each model, and partly due to simply the difficulties in presenting complicated models and results.

[1] Both examples involve panelists as co-authors and are included to simply illustrate that other modeling approaches are available, not necessarily that these specific approaches should be used.

There will be a variety of audiences for NMFS' life cycle modeling. These included: agency personnel, other model developers, model users, and stakeholders. Among these will be disbelievers, skeptics, and supporters. Presentations during model scoping, development, and analysis should be carefully prepared to ensure effective communication. There is a tendency to quickly go to final plots that involved multiple steps (e.g., mean response are shown without explaining they are means of the last 10 years of a 30 year simulation). The panel does note that a model should not be judged on the visual appeal of its graphical user interface. That said, a standard format for presenting input variables and results helps with clarity; the audience gets acclimated to the viewing the essential elements and results.

(6) The difference between precision and accuracy should be maintained and audiences reminded of it.

People often confuse precision and accuracy when using or viewing the results of computer models. Any model developed will be highly precise but will have much lower accuracy. Precision is the exactness of the modeling results, while accuracy is how close the model results are to the truth. Computers, by the nature of their calculations, are very precise; predictions are reported with many digits. It is the model structure (equations) and input values that determine accuracy. Care is needed to ensure audiences do not confuse high precision for high accuracy.

(7) A peer-review panel should be established to provide periodic feedback and advice.

A standing panel[2] should be formed to provide feedback as the model is developed and analyzed. Modeling fish population dynamics requires numerous decisions and often one decision affects subsequent decisions. Quick response feedback and more formal, periodic review may lengthen the development period, but would pay off in the end by resulting in a better, more defensible model. The panel can provide outside feedback on the key assumptions and relationships being used, the strategy for model calibration, validation, and scenario evaluation, and also can suggest data and information from other systems.

Technical

(8) Development of the new model should proceed as a series of iterative steps from the questions to the formulation of a new model.

Model development should proceed as a series of well-documented steps. This is not news to modelers but it is important for transparency in model development and may be useful to the general audience. Also, often modelers go through these steps but do not document them. Part of developing a credible model is transparency in how the model got to the version being used. Often, complicated models suddenly appear to audiences, devoid of the thought processes that lead to the "final" model. Steps 1-3, which are described below, can be done in parallel.

The first step is to select a suite of specific questions. This can be achieved by developing a mapping from water management actions and RPA actions to needed model attributes. We call these attributes to distinguish them from model inputs. Attributes are the time and space scales of the model,

[2] Please ignore any self-serving aspects of a review panel recommending that a review panel be formed.

organization of life stages, processes represented and what drives the processes. A decision can then be made later when the model is better specified as to whether an action is simply changing the value of a model input (e.g., temperature, water flows), or if a mini-model or bridge-model is needed to convert the results of actions and RPA actions into changes in model inputs. Model developers can assign names and labels to variables and inputs however they deem appropriate; however, just because an input with a correct name is available, this does not mean that the input value can be changed to simulate an action. It is the context of how the input is used within the model that truly determines the definition of the input, regardless of how it is named or labeled. Similarly, actions without matching inputs do not mean the action cannot be realistically simulated. Often, changes can be made in existing inputs that sufficiently mimic the effects of the action, or additional models (mini or bridge) can be used to make the transformation from the action effects to changes in model inputs. Thus, developing a mapping of actions to model attributes is important. How the changes in the attributes associated with an action or RPA map to actual changes in model inputs will be determined later.

The second step would be to lay out the existing models in a format so they can be compared across life stages and processes, how the different models were calibrated (parameter estimation and fitting) and validated, and how the models were used in scenario evaluation. The OBAN, IOS, Delta Passage submodel, Shiraz, SALMOD, and SLAM models included in the workshop are an excellent start. One approach is to map all of the models to the same life cycle and study area (spatial map) diagram. This library will serve as a buffet of ingredients for model development. The collection of existing models is a valuable resource because it represents the collective wisdom of others on how to model salmonid population dynamics, and will serve as an easy means for documenting the similarities and differences between the new model and the existing models.

The third step would be to summarize and synthesize the available information and data. Data include: vital rates (growth, mortality, and reproduction), spatial distributions, abundances by life stage, diet information, driving variables (temperature, water flows), etc. These data should be entered into a common database so all people involved in model development use the same version of the data. Meta-data that provide additional caveats and interpretations of the data should be included in the data base. This auxiliary information is often obtained from those who collected the data or have worked on the system for decades.

The fourth step would be to formulate the new model, including alternative formulations for certain key life stages and processes. NMFS would refer to the attributes needed by the actions and RPA, the library of existing models, and the availability of information and data, to build a model. An appropriate balance is needed between the competing forces that push towards more detail being included and those forces that push towards simplification. On one hand, more detail does not necessarily mean higher accuracy. On the other hand, the model cannot be overly restricted to all components having to have extensive supporting data. To the degree possible, immediate feedback from an independent review group would help the process (i.e., the more eyes the better).

The fifth step would be to code the model to enable solutions of the equations. Selection of the coding language and quality assurance of the code (i.e., code is solving the equations correctly) are important. Checks on leakage of mass balance, sensitivity to time step and order of evaluation of processes, real-value versus integer arithmetic and logical statements, and effects of truncations should be part of the code and model development. Test cases with known solutions (e.g., no mortality; constant growth) should be compared to model results under the same conditions. Visualization tools and high-end database management will be needed; Excel should not be used to store and analyze the data or large model output files.

Steps six and beyond involve model calibration, validation, sensitivity analysis, scenario evaluation, and documentation. These are discussed in detail in other recommendations.

Importantly, when a model is "completed," it is likely that new information and emerging areas of concern might necessitate revisiting the original model. For example, data currently available may support only a deterministic model incorporating survival relationships with one or two environmental factors; however, in the future, additional factors affecting survival may be better understood and can be built into the model. Similarly, data acquisition through time might allow stochasticity to be built into the model. This also suggests that part of the iterative process is to identify data that would be particularly useful for model development and to begin the process of collecting those data so that long-term uncertainty can be reduced.

(9) A transparent strategy that utilizes available data should be developed for calibration and validation.

Calibration and validation will affect model credibility and usefulness. Thus, a carefully thought out and planned calibration and validation strategy that includes treatment of uncertainty is needed. Several of the existing models used extensive statistical fitting to data (e.g., Bayesian methods), and some of those concepts and lessons can productively be applied to the NMFS model. The downside to the statistically-based life cycle modeling is that good fits can be obtained to the available data but the accuracy of the model outside of the range of fitting (e.g., to examine the effects of a RPA) can be quite low. There is no assurance that good fit to the present data means high accuracy in predictions under new conditions.

During the model presentations at the workshop, the panel noticed that there was confusion in the audience and within the panel about which information and data were model inputs, which were used to check on intermediate calculations, and true model predictions of population dynamics. This was partially due to incomplete descriptions of the models, necessitated by time and a diverse audience, and also by the presentations themselves. Any NMFS model will be complicated and reality checks on the behavior of components of the model are critical to gauging model realism and accuracy. The approach that key pieces (submodels) in the model are reasonable helps build confidence in the overall model. These comparisons should be made and the results should be clearly described as "checks on the pieces."

(10) Sensitivity and uncertainty analysis integral to the model is not the last step in model analysis.

Sensitivity and uncertainty analyses should be done throughout the model development and application process, not just as the last step. Sensitivity analysis examines model response to small changes in input values, while uncertainty involves examining model responses and variability under conditions of realistic variation in inputs. How variability is imposed on inputs is very important as stochasticity and uncertainty are often confused, and structural uncertainty (wrong model formulation) is ignored.

(11) Careful use of linked models is necessary to minimize propagation of unknown biases and uncertainties into final predictions.

It is very likely that the outputs of other models will be used to generate inputs to the NMFS life cycle model. Examples include using the output of a hydrodynamics model to determine fish routing probabilities, downscaled results from global circulation models, and temperature and habitat models that provide inputs to the life cycle model. There will also likely be mini- or bridge models to link certain water management actions and RPA actions to model inputs. Two challenges are ensuring that models on different scales properly exchange information, and adequate treatment of cascading uncertainty through the linked models.

(12) A parallel effort of data synthesis should be started with the initiation of the modeling effort.

The credibility of the model will depend heavily on calibration and validation, which in turn, will depend on the use of the available data. The available data should be synthesized, with the help and insights from those who collected the data, and entered into a central database. This synthesis should be built upon previous efforts (e.g., Pipal 2005), but also expanded to include not only monitoring-type data but also shorter-term process studies. This is a major undertaking and is often done in a haphazard way and in a rush. The BAs and BOs offer a good source, but detective work will be required to find some of the process studies, especially unpublished study data, and to obtain the raw data from published papers. These data must be entered onto a central database with proper documentation about changes in data collection methodologies and including additional meta-data necessary to document the data set. This will ensure the maximum information content is obtained from the data and that the same versions of the data are used by all involved. There is also much information beyond data (e.g., natural history observations) that should be integrated into the database. As much as possible, the raw data should be obtained because this allows for re-assessment of data variability in the context of the modeling, which may be different than how the variability was summarized as part of the original study.

(13) Critical aspects of the developed model will be: density-dependence, time-stepping, spatial grid, routing into and through the Delta, and ocean growth and survival.

Several of the models presented at the workshop (IOS, Shiraz, SALMOD, and OBAN) use the same approach of representing life stage survivals as Beverton-Holt (or Ricker) like functions (density-dependence). Environmental covariates (e.g., water temperature, flow) are then added to these functions based on correlation analyses. The Panel had several cautions about using this approach for a model designed to address water management and RPA actions. First, these functions are specified for multiple life stages without much consideration of how the density-dependence propagates through the life cycle. We know that a series of Beverton-Holt functions in sequential life stages results in a global Beverton-Holt relationship (Brooks and Powers 2007); yet, none of the presentations showed a global spawner-recruit relationship as output. It seems that each stage is dealt with quasi-independently. How the output of one life stage, modulated for density-dependence, affects the subsequent life stages must be carefully evaluated.

Second, estimation of the productivity and carrying capacity parameters of the Beverton-Holt functions can be ad-hoc and yet is critical to which and how the environmental variables get incorporated and how the model will respond to new conditions.

Third, change in the growth rates of the fish is not treated explicitly, but somehow gets reflected in the productivity and/or carrying capacity parameters or in the covariates (e.g., temperature-dependent survival). Growth rates, which influence migratory behavior and duration of salmon in each life stage, are important responses to environmental conditions and potentially to some of the RPA actions (e.g., flooding of the Yolo Bypass).

Finally, the routing of individuals through the system, like growth, is also not directly obvious in the simple Beverton-Holt approach. How individuals traverse the system is a critical aspect of the model and should be robustly represented and reactive to changed conditions, rather than fixed fractions. The Shiraz model offers an approach for explicit routing of the population and its subcomponents through the system within a Beverton-Holt approach.

We recommend that the NMFS model be developed in two versions: simple and full. The simple version is for testing ideas and general behavior of the model. The simple model can be based on an idealized spatial grid and allow for density-dependence to be easily turned on and off. Dr. Steven Lindley presented a flow diagram at the recent NRC committee meeting that could provide the basis for such a simplified model. The spatial resolution was river, floodplain, delta, bays, and ocean. Another example, developed by Dr. Anderson of the review panel, is shown in Figure 1. These simplified models can be populated with simple probabilities for routing alternatives and survival, and used for exploratory modeling in parallel with the full life cycle model.

The full model should be based on geography, rather than more generalized spatial boxes, and allow local conditions to affect appropriate components of the population(s). This is necessary to allow for future conditions to be simulated in hydrodynamic and other models (e.g., CALSIM) to be easily inputted into the full life cycle model. The spatial grid for the full model should be designed up front to be compatible with hydrodynamic and other models likely to be used. NMFS should prepare a strategy document prior to model development that lays out their plan for simulating water management and RPA actions using hydrodynamic and other models and how they can be mapped (either directly with mini-models and aggregation) to the spatial grid of the full model.

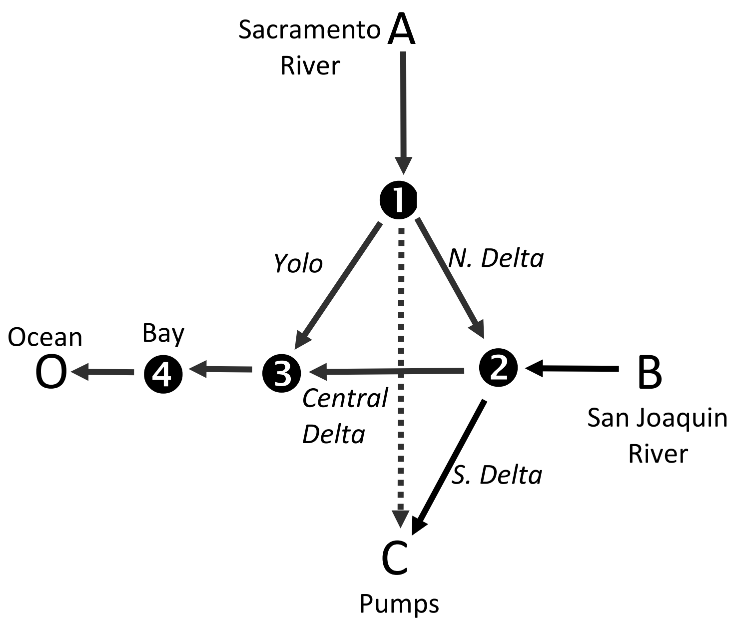

Figure 1. Illustration of a simplified model of fish and water routing through the Bay Delta system. Solid arrows denote surface conveyance, dashed arrow denotes tunnel conveyance. Letters denote terminal points and numbers represent confluences, diversions, and habitat transitions.

The NMFS model must be able to generate annual values of all state variables, allow for time-stepping within the year for some processes, simulate routing of fish in the system, and produce spatial distributions. This can be tricky with stage-based models (including simulation versions) because the computation of stage abundances each time step in locations does not necessarily mean that the abundances all occur at the same time in those locations. The use of other models, such as hydrodynamic models, to provide inputs to the NMFS model exacerbates this time and space scale issue. For example, should one compute a monthly, weekly or daily average from the output of the hydrodynamics model and use different time periods of averaging for different regions on the model grid? One interesting approach to within-year time-stepping is the IOS algorithm of simulating annual changes using a within-year cohort approach. Cohorts are defined, say by splitting up the timing curve, and then using the cohorts to obtain a weighted-average annual survival rate. Shiraz also attempts to deal with resolution within the annual time stepping. Other approaches are to have nested time steps, with certain processes being updated more frequently than others (e.g., routing maybe daily or weekly, summed and then used annually in the Beverton-Holt functions). The IOS Delta passage submodel may offer some good ideas. To the Panel's knowledge, none of the models presented at the workshop adequately provide an entire set of algorithms needed.

Ocean dynamics are poorly known but important. The panel is aware that NMFS is developing an ocean and fishery submodel for other locations that would inform the ocean model in a NMFS CV model. Ocean dynamics have a strong effect on salmon survival, age at maturation and total abundance returning to natal rivers. Recent research along the California, Oregon, and Washington coasts has revealed important factors affecting Chinook salmon, largely through bottom-up (food related) processes (Lindley et al. 2009). However, in contrast to the potential for high growth rate and survival in coastal marine waters, Chinook salmon rapidly migrate through the estuarine waters of San Francisco Bay where feeding and growth rates appear to be much lower than in coastal marine waters (Macfarlane 2010). Chinook growth in the estuary was related to higher salinity and reduced input of freshwater.

Density-dependence has been a controversial issue in population dynamics for decades (Rose et al. 2001), but there is growing evidence that it can affect salmon growth, age at maturation, and survival, even at relatively low population abundances (Ruggerone et al. 2010). In theory, density-dependence might seem to have negligible effects on populations having very low abundances, such as those protected by the ESA in the Central Valley. However, four key factors suggest density-dependence might still play a role among ESA populations: (1) degradation and loss of habitat will reduce the capacity and productivity of the watershed for supporting natural salmon; (2) watersheds are often stocked with highly abundant hatchery salmon that compete for resources; (3) salmon compete with other species that may be highly abundant; (4) spatial aggregation behavior can result in localized density-dependence. For example, in the Snake River Basin efforts to supplement natural spring Chinook salmon populations led to surprisingly strong evidence for density dependence in the streams even though abundances of the ESA populations were still quite low (e.g., see studies by Carmichael in www.fws.gov/lsnakecomplan/). In these streams, annual salmon smolts produced per spawner declined sharply with increasing numbers of spawners during the past 13 years, indicating that the degraded habitat could no longer support large populations. Zabel et al. (2006) also found strong support for density-dependence at the egg-to-smolt stage for the entire Snake River spring/summer Chinook ESU. In the Sacramento River, an experimental caged-fish study indicated growth of natural fish was reduced when hatchery salmon were introduced to the cages, but the investigators did not observe displacement of natural fish by hatchery fish (Weber and Fausch 2004, 2005). Density-dependence has also been observed in coastal marine areas in response to hatchery releases (Levin et al. 2001, Levin and Williams 2002) or to high abundances of other salmon species (Ruggerone and Goetz 2004). The influence of density-dependence in the ocean tends to be greater during periods of lower ocean productivity.

(14) Consideration of life history variation and spatial distribution, in addition to usual focus on population abundance, is needed in order to address the VSP criteria.

Life cycle models are single-species and often focused on abundance, with life history variation and spatial dynamics of secondary consideration. The model should be developed with the long-term goal of eventually including the effects of life history variation and spatial distribution. Use of different spawning areas, the timing of the upstream migration of spawners and downstream migration of smolts, the areas used for rearing (fry to smolt transition), and the role of jacks are all potentially important issues related to life history diversity and spatial distributions. Using otoliths, Miller et al. (2010) recently showed that naturally-produced Chinook in the CV likely produce various life history types.

There is limited quantitative information on life history variation so the implications of life history variation will necessarily be exploratory. However, recent work has shown that extinction risk is increased as the diversity of populations (as expressed by demographic correlation) is decreased (Moore et al. 2010). Spatial aspects of the population dynamics should also be examined for its realism. Model output is frequently aggregated over space; model outputs on spatial distributions should be carefully examined, as this an important part of the VSP. Modeling the movement of the fish will be challenging but important to get reasonable spatial dynamics.

Related to life history variation are the effects of hatchery fish. A NMFS model should have the capability to keep track of hatchery fish separately from natural-spawned fish. Hatchery fish can have different ages at maturation, sizes at key life stages, migration routes, and survival rates than naturally-spawned fish, and under some circumstances, can comprise a significant fraction of returning fish. The importance for the model is that we can expect residence time and migration period (season) of natural Chinook in the river and Delta to be much more variable and often longer than hatchery Chinook, which are larger at release and tend to move through system (and San Francisco Bay) quickly. Straying of hatchery salmon to the spawning grounds, and potential effect on fitness of the naturally spawning population, should be also be considered.

Ownership

(15) An important consideration for a NMFS model is that NMFS must have complete ownership of the model[3].

Any life cycle model for salmonids for the Central Valley used by NMFS should be a NMFS model. NMFS can, and should, make use of previous modeling efforts but each and every component and formulation of the model should be a NMFS decision to include that component and specific formulation. Input and feedback are critical but NMFS makes the final decision.

The degree to which the existing models are proprietary also raises an issue about ownership. NMFS must have complete access to all source codes for its model, and cannot be in a situation of having to hire developers of the original model to make changes. The NMFS life cycle model must be a stand-alone model and code that is completely under their control and their responsibility.

(16) Manpower and resources

Developing and applying life cycle models are time consuming and require certain specific skills. The effort involved in population modeling is often underestimated. A NMFS salmonid model must be developed carefully and with attention to details because the results can influence major decisions and the modeling will be under careful scrutiny. The Panel emphasizes that the quality of the modeling will depend on sufficient resources and that people with the needed skills will be available (and not stretched too thin). In addition to a modeling team, there should also be a complementary team of people who know the data, salmon ecology, and hydrodynamics. The data aspects of the modeling must be done rigorously as well, and will require a significant effort.

[3] The Panel uses the term "ownership" to mean that NMFS is responsible for all and every aspect of the model. Ownership means that NMFS should not be dependent on other groups or model codes for their model. Ownership, in this regard, does not mean any loss of transparency or lack of sharing of the model at appropriate times.

6. Answers to Charge Questions

1) Which model(s) are most appropriate for informing NMFS of the effects of water operations and prescribed RPA actions on salmonids at various life stages and at the population level? *(See comments 3, 8, and 13)*
    a) What are the strengths and weaknesses of the model(s)?

Short Answer: The Panel concluded that none of the existing models were sufficiently well suited to examining the water management and RPA questions to justify their selection as the model to use. Each of the models had strengths and weaknesses, and when taken all together, provide a strong foundation of processes, process constructs, how to deal with space, calibration, and other aspects of modeling, from which an appropriately-scaled model can be formulated. This conclusion is premised on two major assumptions: (1) the Panel understood the questions to be addressed by the model, and (2) the Panel had sufficient knowledge of the models. Panel members have served on earlier panels that reviewed the BOs and RPA actions, and thus are familiar with the questions to be asked of the modeling. The documentation provided on the existing models was useful but incomplete, the presentations were not designed to facilitate inter-model comparison, and one day is too short to complete a comprehensive and technical comparison of these models. Despite these limitations, the Panel determined they knew enough to make a judgment about the models based on background reading material, the presentations, and the panelists' general knowledge about life cycle modeling. Thus, armed with their knowledge about the questions and the models, the Panel determined that a new model should be developed, rather than trying to modify one of the existing models.

The models presented at the workshop illustrated the wide diversity of possible approaches. The SLAM model was really bookkeeping software tailored to developing life cycle modeling, and the SLH was a life history model that could be developed into a life cycle model with additional effort, but more likely most useful as a mini-model to parameterize the life cycle model. Various subsets of the Shiraz, IOS, SALMOD, and OBAN, while different from each other in important ways, also shared several common features. All taken together, they provide an excellent start for a NMFS model. Selecting a single existing model is also not recommended because there were issues among all the models about documentation and the availability of source codes.

b) What are key parameters and performance measures captured in the model(s)?

Short Answer: The Panel notes that the existing models, and most all population dynamics models, should be viewed as life stages that individual fish progress through over a lifetime (i.e., a life cycle diagram) overlaid on a map showing the spatial boxes. Four fundamental processes govern the rate that individuals progress through the stages: growth, mortality, reproduction, and movement. Mortality and reproduction directly affect numbers of individuals; growth affects body size, which can then influence mortality and reproduction; movement places individuals in locations that differ in their conditions (habitat), which affects growth, mortality, and reproduction. Models mostly differ in their spatial resolution, time step, the definition of life stages, and how growth, mortality, reproduction, and movement at each life stage are represented. All models, including existing and the new NMFS version, should be described using this common framework. Every model description should start with a spatial map cross-referenced to the life cycle diagram, and then be described using these four processes through each life stage.

Key performance measures varied greatly over the existing models, from extensive Bayesian fitting to measured survey (stage) abundances to qualitative descriptions how model behavior was realistic without any empirical data presented. The Panel cannot specify the exact performance measures that should be used without knowing how the questions intersect with the structure of the model and the quality and quantity of the available data. Calibration and validation will also require certain model-data comparisons. It is also important to ensure adequate model performance is expected under scenarios, which often involve conditions outside the domain of calibration and validation.

Some general performance measures would be expected: comparison of model predicted and observed stage abundances, size at stages, stage durations and mortality rates, stage durations, fraction mature by age, ocean residence times and survival. Other performance measures depend much more on the specifics of the questions, model, data, and scenarios: spatial distributions by stage and month, variation in run times, and movement routes.

Evaluation of model performance involves model-data comparisons but also diagnostics. Model-data comparisons should factor in the variability in both. Diagnostics are model outputs, and intermediate results within the model (e.g., survival in a particular reach or of a day-cohort), that we have knowledge about reasonable values but may not have the actual sampling data. Brood tables and life stage summarized by year and year-class of model output are useful model diagnostics. The more checks-and-balances on model performance, both quantitative and qualitative, the more confidence in model results and the more information can be provided on the limitations of the model to address certain questions. For example, even without spatial data spanning multiple years, we know roughly what realistic spatial distributions are. If spatial distributions are examined as a diagnostic, then one can use appropriate caution when interpreting the results of simulating water management or RPA actions that depend on a certain degree of realism in spatial distributions.

c) How can this/these model(s) be applied to address the multiple timescales associated with RPA decisions and operations?

<u>Short Answer:</u> A suite of mini-models or bridge models can provide the needed link between operations and RPA actions and the life cycle model. Typically, model outputs are easier to aggregate to input to the population model than to disaggregate. However, aggregation involves loss of information, usually on variability (e.g., daily average water temperature from hourly predictions) and this should be carefully examined.

In addition, the life cycle model should be developed to allow for modular simulations (specific life stages or spatial boxes) and for both short-term (weeks, months, a year) and long-term (decades) simulations. Inputs should be able to be specified as changing in time and space. This is important to consider at the outset when coding the model.

d) What are the technical constraints to the implementation of the model(s) and the feasibility to address them (e.g. transparency of the model, data set(s) availability, model parameter uncertainties and sensitivities, etc)?

Short Answer: The technical constraints of modifying an existing model and developing a new model are numerous, but manageable if model development proceeds in a systematic and clearly documented manner. Many of the technical constraints were discussed in the general recommendations. In particular, the transparency of the model would benefit from antecedent charts that show how various components and methods (e.g., data-fitting, linkage to hydrodynamics models) of the new NMFS model relates to the existing models. Otherwise, a new NMFS model will be just another model in the mix and will lead to more confusion when various models generate different (sometimes contradictory) results.

Related to transparency is model documentation. None of the existing models had comprehensive documentation in one document, and a few models had sufficient documentation even when multiple documents were reviewed. A complete model description needs to be available and updated periodically.

Another major technical issue not discussed in detail in the General Recommendations was the coding of the model. We urge careful consideration of the coding of the model at the outset of model development and that code decisions include what the model might look like in 5 years. Computing power should not be a constraint on the biology included in the model (i.e., unacceptable to justify a 3 spatial box model based on run times). Excel should be avoided as the computing engine; R is reasonable but can be limiting; a sequential language (C++, FORTRAN) is the most flexible but also the most effort. The decision of a coding language also depends in the expertise of the modeling team. The key is that the numerical engine be carefully considered.

The NMFS model will necessarily have to be spatially-explicit (1-D) at some level of resolution, generate annual predictions, be capable of calculating some processes at sub-annual time steps, and be capable of simulating 100 years. The spatial resolution is a difficult technical issue because the spatial resolution dictates other aspects of the model. The finer the resolution the more data are needed to seed the many spatial cells. A resolution compatible with hydrodynamics grids is helpful for easily using hydrodynamics output in the life cycle model, but may not be too fine from the biological and data views. A resolution too coarse will lead to inaccurate predictions of water operations and RPA action effects because important spatial details of the actions can be lost when imposed in a coarse model. Spatial variation can be represented explicitly by dividing an area into multiple spatial cells, or implicitly by having portions of the individuals in a cell experience different environmental conditions (e.g., temperature) on the same time step.

The biological resolution or currency in the model, and how movement is represented, need to be carefully considered. Options for currency include: classes (age and stage), cohorts, super-individuals, and individuals. Once a model is spatially-explicit, then movement must be dealt with. Movement can be from transport or behavior, or a combination of both. Movement is easiest in an individual-based model but the Panel does not recommend an individual-based approach because of high data requirements. Stage class or cohort, or cohorts within classes, seems the best approach. This will complicate representing movement on the spatial grid.

The NMFS model should not be developed to include the finest resolution ever needed in space and time. Rather, for the questions that require detailed spatial or temporal resolution and specific life stages, a mini-model can be developed and used to bridge (average, aggregate) from the operations and RPA actions to the inputs of the model. For example, a juvenile stage model may be needed in the vicinity of the Delta Cross Channel for a specific month. This can be used to generate outputs that can then be used to change the inputs of the coarser life cycle model, without the life cycle model needing such a fine resolution near the Delta Cross Channel.

2) How can multiple specific models be linked to represent the whole life cycle to inform NMFS in determining the effects of water operations and prescribed RPA actions on salmonids at the population level? *(see comments 2 and 11)*

<u>Short Answer:</u> The Panel does not recommend direct linking (i.e., outputs of one model become inputs to the next model) of various combinations of the existing life cycle models. Each of the existing life cycle models should be deconstructed into its components, and then these components can be re-assembled in a new model. Each of the existing models has nice features but none provide a complete, self-contained package that is appropriate for the model needed by NMFS. One of the existing models may be close to what is needed (based on the questions) on how it represents ocean dynamics, while another existing model has an appropriate routing of individuals around and within the Delta. The new model can use these and thus “link” them in the new model. In addition, there are other models available that focus on specific life stages, habitat models, and models that will be used to generate inputs (e.g., temperature, hydrodynamics) to the new population model. These must be evaluated independently for the realism and performance of the new model and then can be inserted (another form of linking).

3) How well can the models be adapted for species other than what the model was originally developed?

<u>Short Answer:</u> All of the existing models, as well as a new NMFS model, are flexible and can be adapted to new species. The issue is a matter of effort. These types of models are constantly evolving by being improved as new information becomes available and as they are tailored to evolving and new questions. SLAM is designed to be used for new species but is necessarily generic until it is seeded with species-specific information, which can be a small or large effort. Without getting into the details of each of the existing models, it is difficult to determine if certain aspects of these models are developed and coded such that adapting the model to a new species would be simple or involve a major overhaul. For example, changing the temperature dependence of growth rate is likely easy. However, if the new species has different habitat usage patterns or movement patterns, this can require changing the resolution of the spatial grid or the number of spatial boxes. Changing the spatial arrangement in an existing model can require re-formulating most of the model. Changing the spatial resolution would involve re-estimating the spatially-explicit driving variables and any habitat variables specific to spatial locations, and could even require changing the time step of the model to maintain stability and this then can affect how all of the biological processes in the model are represented. Of course, it can be done,

but at some point it becomes a new model, rather than the adaptation of an existing model. At the high level, any species can be modeled, as they are governed by growth, mortality, reproduction, and movement in a life cycle.

4) How can the models best fit into a decision-making framework for using life cycle models (at appropriate temporal and spatial scales) to adapt water operations and prescribed RPA actions on individual and multiple species? *(see comments 2, 5, 6, and 10)*

Short Answer: Decision-making frameworks can vary from simply passing model results to people who make decisions to an integrated system whereby the life cycle model is directly coupled to economics and policy models. The life cycle model generates results that go into the economics model, which then goes into the policy model, and decisions can then loop back and affect the life cycle model simulations (i.e., fully dynamic).

Critical aspects of presenting model results for decision-making are ensuring the results are properly interpreted, caveats and strong aspects are known, results are optimally simplified without too much loss of information, and information about uncertainty is included. This is a formidable challenge in both how to propagate uncertainty and in effective communication.

A semi-formal decision-making framework coordinated by ESSA (www.essa.com/projects/da/index.html) was used by NMFS to evaluate competing passage and life cycle models for Columbia River salmon. The effort had mixed success and was eventually abandoned. In its place, NMFS initiated a cooperative regional effort to develop passage and life cycle models. The resulting passage model (http://www.cbr.washington.edu/compass/) is more transparent and regionally supported than the models used in the ESSA analysis. An important component of this additional acceptance was the acquisition of 10 years of empirical data that helped reduce the uncertainty about survival through the hydrosystem in the Columbia River. A model to be used to evaluate actions under Biological Opinions should be a NMFS model and NMFS needs to be responsible for all aspects of the model. This does not mean any lack of transparency; stakeholders and the public must be kept informed of progress in model development.

Transferring information from models to decision makers involves more than presenting the full suite of model results. Models are also a way to convey essential elements of the real complex system. However, models reviewed by the panel have considerable detail and so essential features are often difficult see extract from the details. A similar problem was encountered when some panel members reviewed models developed for the Central Valley Biological Opinion on salmon. Furthermore, in a decision making framework the Central Valley is unique from other systems because fish from the Sacramento and San Joaquin rivers both enter the Delta and can pass through multiple routes to the ocean. These complexities do not exist in most river systems. The multiplicity of passage routes makes the impact of RPA actions dependent on the routing of fish through the system. The panel suggests that simplified models, aggregating results from the complex models, have value in decision making.

Concluding Remarks

The Panel strongly endorses NMFS pursuing the development of a life cycle model for CV salmonids to examine water management and RPA actions. The development and application of such a model is long overdue. The usefulness of the modeling will depend on a careful, transparent, and well-documented approach that results in a NMFS-owned model, and whose relationships to existing life cycle models, to water management actions and RPA actions, and to other (hydrodynamics, CALSIM, habitat) models, is clear. Whether the new model clarifies the issues and helps to answers the water management and RPA questions or becomes another model, mysterious to most that further confuses discussion, depends on, the quality of the model (necessary condition), but also on how the model is developed, documented, analyzed, and described (sufficient condition).

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Appendix A. Background reading materials provided to the panel prior to the workshop.

Each independent workshop panelist was provided the following documents prior to attending a one-day public meeting.

OBAN

Hendrix, N. (2008). A Statistical Model of Central Valley Chinook Incorporating Uncertainty: Description of *Oncorhynchus* Bayesian Analysis (OBAN) for winter run Chinook. R2 Resource Consultants, Inc.

Lessard, R.B, N. Hendrix, et al. (in press). Environmental factors influencing the population viability of Sacramento River Winter Run Chinook salmon (*Oncorhynchus tshawytscha*).

Shiraz

Scheuerell, M. D., R. Hilborn, et al. (2006). "The Shiraz model: a tool for incorporating anthropogenic effects and fish-habitat relationships in conservation planning." Canadian Journal of Fisheries and Aquatic Sciences 63(7): 1596-1607.

IOS

Bartz, K. K., K. M. Lagueux, et al. (2006). "Translating restoration scenarios into habitat conditions: an initial step in evaluating recovery strategies for Chinook salmon (*Oncorhynchus tshawytscha*)." Canadian Journal of Fisheries and Aquatic Sciences 63(7): 1578-1595.Winter-run Chinook IOS and Delta Passage Model

Cavallo, B., P. Bergman, et al. (2011). Interactive Object-oriented Salmon Simulation (IOS) for the NODOS. Cramer Fish Sciences.

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WEAP – SALMOD

Bartholow, J., Heasley, J., et al. (2001). SALMOD: a population model for salmonids: user's manual. Version W3.

Fall Chinook Salmon Life Cycle Production Model Report to Expert Panel

Yates, D., D. Purkey, et al. (2009). “Climate Driven Water Resources Model of the Sacramento Basin, California.” Journal of Water Resources Planning and Management 135 (5): 303-313.

Publications based on the WEAP model http://www.weap21.org/index.asp?doc=16

SLAM

http://www.nwfsc.noaa.gov/trt/slam/slam.cfm

Steelhead Life-History Modeling

Satterthwaite, W. H., M. P. Beakes, et al. (2009). "Steelhead Life History on California's Central Coast: Insights from a State-Dependent Model." Transactions of the American Fisheries Society 138(3): 532-548.

Satterthwaite, W. H., M. P. Beakes, et al. (2010). "State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley." Evolutionary Applications 3(3): 221-243.

Additional Reports

National Marine Fisheries Service Biological Opinions Page

Summary Presentation - National Marine Fisheries Service, 2009 Biological Opinion on the California's Central Valley Project

NMFS OCAP Effects Summary and RPA Actions

National Research Council Committee on Sustainable Water and Environmental Management in the California Bay-Delta (2010). "A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta".

CALFED Independent Review of a Draft Version of the 2009 NMFS OCAP Biological Opinion. January 2009.

U.S. Fish and Wildlife Service Biological Opinion Page

Appendix B. Agenda of the workshop meeting held April 13 in Sacramento.

Introduction

8:30 – Welcome remarks - Delta Science Program

8:45 – Opening Remarks from NMFS (Steve Lindley)

Model Presentations

9:30 – OBAN (Noble Hendrix)

10:30 – Winter-run Chinook IOS and Delta Passage Model (Brad Cavallo)

11:15 – Shiraz (Mark Scheuerell)

12:00 – Lunch

1:00 – SLAM (Paul McElhany)

1:45 – WEAP-SALMOD (Vishal Mehta, Charles Young and Lisa Thompson)

Use of SALMOD in a Decision-Making Framework for Adaptation of Water Operations: Answers to Questions Regarding OCAP RPA Actions for the Salmonid Integrated Life-Cycle Models

2:45 – Steelhead Life-History Modeling (Will Satterthwaite)

Discussion

3:30 – Panel and Presenter Discussion

Public Comment and Concluding Remarks

4:45 – Public Comment and Concluding Remarks

Adjourn (5 p.m.)