ISAB

Independent Scientific Advisory Board
for the Northwest Power Planning Council
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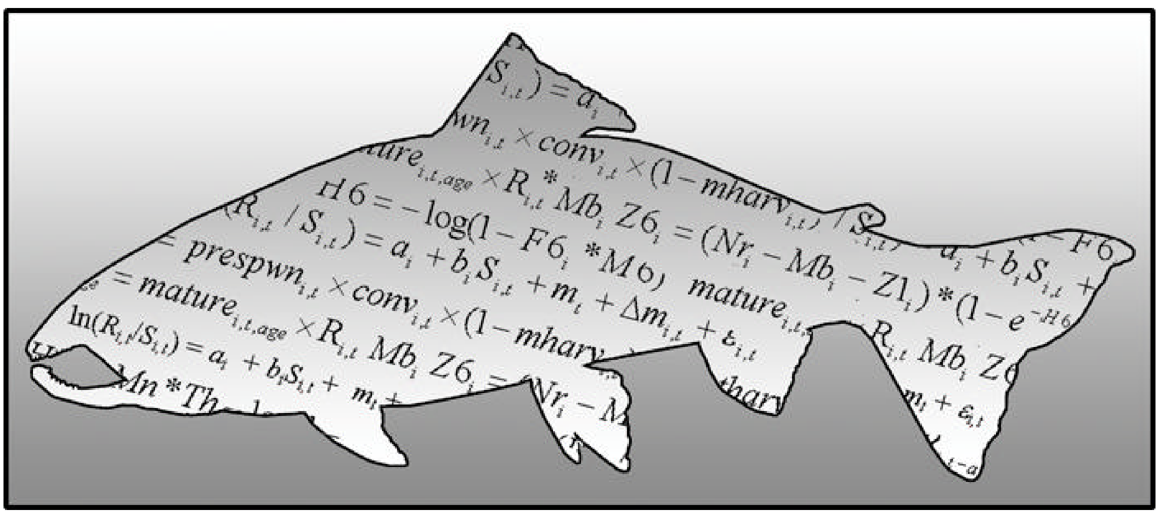
Model Synthesis Report

An Analysis of Decision Support Tools Used in Columbia River Basin Salmon Management



Executive Summary

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Purpose of the Project

The major analytical efforts underway to support decision-making for salmon restoration in the Columbia Basin include NMFS' Cumulative Risk Initiative (CRI), the Plan for Analysis and Testing Hypotheses (PATH), the Northwest Power Planning Council's use of the Ecosystem Diagnosis and Treatment protocol (EDT), the United States Forest Service's and Bureau of Land Management's effort undertaken for the Interior Columbia River Basin Ecosystem Management Plan Bayesian Belief Network (ICBEMP-BBN), and the Columbia River Intertribal Fish Commission's COHORT model (CRITFC). Within the region, conflict has developed over the role these models should play in the decision-making process and the need for multiple modeling approaches. Decision-making could be hampered if the region becomes engulfed in a "collision of models," with various interest groups and agencies advocating the conclusions that best support their interests and mandates. The ISAB undertook this project to clarify the questions or problems that each model was designed to address, to provide an overview of each of the models and a synthesis that describes both consensus conclusions and areas of disagreement, and to assess the roles models play in the decision-making process.

There are now at least three distinct philosophies of modeling represented in the models available for decision support in Columbia Basin salmon management. These philosophies are: (1) decision-analysis, embodied most clearly in PATH-FLUSH and PATH-CRiSP, (2) statistical, embodied most clearly in CRI, and (3) expert-system, embodied most clearly in ICBEMP-BBN and EDT.

Of the three approaches, the decision-analysis approach is most closely directed at providing management advice, and it is the most formal about factoring uncertainty into the analysis. This modeling approach has the potential to be the most useful to decision-makers.

The decision-analysis approach, however, is very difficult to implement successfully. Its success depends crucially on the engagement of the actual decision-makers in framing the questions that need to be answered, identifying the management options that are under consideration, and in defining the "values" put on the various possible outcomes. Such engagement and communication is difficult to achieve in the institutional setting of Columbia Basin salmon management, where there is so much fragmentation of decision-making authority.

The statistical approach is scientifically the most classical of the three, and can operate with a large degree of detachment from policy. It proceeds by testing hypotheses and estimating life history parameters with available data. This has the advantages of clarity, rigor, and empirical objectivity. The limitation of this approach is that the scope of the questions that can be answered with satisfactory conclusiveness is restricted by the availability of data. In a domain that is data-poor, too many pressing questions may go unanswered.

Expert-system approaches fill gaps in the data with expert opinion. In the context of the salmon problem, expert opinion allows consideration of the most concrete menu of specific options for actual management. Expert opinion is, admittedly, a weaker basis for scientific prediction than is a mathematical relationship validated with an archive of quantitative empirical data. It is important to recognize, however, that at the level of spatial resolution and environmental detail required to make salmon management decisions, there are no available validated mathematical formulae for predicting reliably the effects of management actions on salmon, and there is no adequate data archive for deriving such formulae. In this light, the expert-system approach may well be a reasonable and practical method for providing tentative answers to some management questions that need to be addressed quickly.

Synthesis of the Answers to the ISAB's Questions

In undertaking this project, the ISAB requested the assistance of the principal scientists involved in each analytical approach. We asked that they 1) provide written responses to a series of questions about their modeling approach, 2) give an oral presentation of their responses and participate in a discussion of the responses with the ISAB, and 3) participate in a panel discussion with the ISAB and the representatives of each of the modeling approaches. The following is a synthesis of their responses to our list of questions. A more detailed summary is presented later in the report (Table 1) and the actual written responses are included in Appendix III.

What is the purpose of your modeling effort? What questions or problems were your models designed to address?

Purposes of the decision support systems (models) are different. Two (PATH-FLUSH and PATH-CRiSP) are primarily designed only to evaluate Snake River salmon recovery actions including breaching the lower four Snake River dams, increased transportation, and reduced harvest. Two (ICBEMP-BBN and EDT) are primarily designed to evaluate large-scale habitat management alternatives across the landscape of the Columbia River Basin and three (CRITFC, CRI and PATH-EM) are primarily for prediction of trends in populations of salmonids based on counts of fish and rates of change in population parameters.

What kinds of information or data are needed to run your model?

Data needs are different, because the purposes of the models are different. PATH-FLUSH and PATH-CRiSP models concentrate on estimating survival based on flow and other data as fish enter the lower Snake River. ICBEMP-BBN and EDT concentrate on predicted effects of habitat changes over large areas based on spatial habitat data. CRITFC, CRI, and PATH-EM concentrate on predicted trends in sizes of populations based on fish counts and rates of change of population parameters (e.g., survival rates) in the presence of various management actions. One characteristic common to all of the models is that information required to run the models includes not only primary data measured by documented procedures, but also derived values each depending on yet other (perhaps undocumented) assumptions and 'models.'

What are the assumptions of your model?

Not only are the purposes and data needs different among the models; the models depend on different assumptions made by the respective developers concerning the state of nature. Some of the key assumptions made are highlighted in Table 1, and the presenters described others (Appendix III). Two of the models, ICBEMP-BBN and EDT, are "expert systems" depending heavily on opinions (i.e., assumptions) expressed by panels of experts. All of the models implicitly assume that future climate and ocean conditions will be like those in the recent past.

What are the strengths and weaknesses of your model?

Given that purposes, data needs, and assumptions are different, it is not surprising that the models have different strengths and weaknesses (Table 1). Some involve complex interactions of physical and biological factors (ICBEMP-BBN, EDT, PATH-FLUSH, and PATH-CRiSP), others (CRI and CRITFC) depend on relatively simple mathematical procedures that can be easily programmed and duplicated, while PATH-EM fits somewhere in-between. Simplicity and complexity are each simultaneously a strength and a weakness. The simpler models allow relatively more direct point estimates of life history parameters under a given set of assumptions, but lack the ability of the complex models to help understand mechanisms of cause and effect relationships. The more complex models deal better with the comparison of management alternatives, but usually can only rank alternatives on their expected benefits. It would be nice of course to have the advantages of all the decision support systems in one 'model', but this seems to be impossible.

How does your model address uncertainty?

Only one model (CRI) reported an attempt to deal with variation in the data due to sampling (observational error) so that confidence intervals can be placed on predicted values. However, CRI was not totally successful in this attempt and along with EDT, PATH-EM, and CRITFC, performed sensitivity analysis (e.g. presented "best case-worst case" outcomes of actions). The other models, ICBEMP-BBN, PATH-FLUSH, and PATH-CRiSP, utilized probabilistic arguments either by standard procedures or Bayesian methods to assign probabilities to expected outcomes. None of the models address the issue of the feasibility of implementing management actions in the face of social and economic constraints.

All models make predictions. Why do you think your model's predictions are accurate?

In comparison of major management alternatives, all of the models depend primarily on the relative rank of predictions, not accuracy of the actual predicted numerical values. The rank orders of effects of alternative actions were judged to be accurate by the model presenters.

How does your modeling effort relate to or contrast with the other modeling efforts?

The modeling efforts have very different objectives. Both EDT and ICBEMP-BBN rely on expert opinion to rank effects of habitat changes over large areas, but EDT gives finer scale analyses. CRI, PATH-EM, and CRITFC attempt to predict the trends of stocks of fish, but with different approaches and information. PATH-FLUSH and PATH-CRiSP concentrate on analysis of only two Snake River ESUs. Never-the-less, the general conclusions when faced with the same objectives and when based on more-or-less the same information are often in close agreement with respect to the predicted rank order of effects of management alternatives. As PATH-FLUSH concluded "The decision analysis of PATH showed which actions were most likely to benefit the stocks under the widest range of assumptions. Analyses using the same data and the Leslie matrix model advocated by CRI give strikingly similar results about the relative effectiveness of the proposed alternatives in preventing extinction and achieving recovery of listed Snake River stocks."

What is the efficacy of dam breaching or draw down to natural river levels for delisting ESA species and restoring diverse and productive populations of native fishes throughout the Columbia River Basin?

There is general agreement among the models that breaching dams is effective in restoring mainstem habitats to the benefit of listed fall chinook and breaching would provide significant benefits to both Snake River fall and spring listed stocks. All models also agree with the obvious and important conclusion that breaching dams on the Lower Snake River will do little or nothing to help the other ten listed ESA species. With respect to the Snake River spring chinook population, there is general agreement among the PATH models that dam breaching or draw down are better than transportation (with the dams in place) as a recovery measure. CRI and CRITFC conclude that survival gains from other factors such as tributary and estuarine habitat improvement are needed to allow the Snake River spring chinook population to rebuild, even with dam breaching. ICBEMP-BBN is not useful in judging the efficacy of dam breaching.

What is the efficacy of hatcheries for delisting ESA species and restoring diverse and productive populations of native fishes throughout the Columbia River Basin?

No satisfactory conclusions were given concerning the efficacy of hatcheries for delisting ESA species. Only EDT and PATH-EM seems to have taken an initial look at modeling the effect of reduced hatchery production (for wild steelhead in the Snake River).

What is the allocation of harvest and harvest levels needed to delist ESA species and restore diverse and productive populations of native fishes throughout the Columbia River Basin?

The effect of changing harvest received varied and limited attention by the modeling efforts. CRI concluded that reducing harvest would allow only three ESUs (Fall Chinook in the Snake River, Upper Willamette Chinook, Lower Columbia Chinook) to grow, a conclusion not much different from the PATH determination that harvests were not significant contributors to declines in survival of Snake River Basin populations after 1974, or the CRITFC note that elimination of all harvest, by itself, is not sufficient to maintain or rebuild spring chinook populations in the Snake River or above Priest Rapids dam. ICBEMP-BBN, EDT, and PATH-EM have not attempted to assess impacts of harvest alternatives on ESA stocks.

What is the efficacy of restoration of tributary and mainstem habitat for delisting ESA species and restoring diverse and productive populations of native fishes throughout the Columbia River Basin?

The two broad scale habitat models, ICBEMP-BBN and EDT, both agree that over the long term improving tributary habitat is effective in maintaining or restoring abundance and distribution of tributary populations. The rather obvious conclusion is supported that breaching dams was effective in restoring mainstem habitats to the benefit of listed Snake River fall chinook. CRI related salmon productivity to characteristics of tributary habitat. PATH, in contrast, concluded that tributary habitat degradation was not responsible for the decline in Snake River stocks following the construction of the lower Snake River dams.

What advice would you give decision-makers on how they should use your model to support decisions regarding salmon recovery in the Columbia River Basin?

The decision support systems have different strengths and weaknesses and policy-makers would be well served by drawing on all of the available analytical tools. Six of the seven presenters implied that their model should be used in conjunction with other models, because in the words of one “No model does it all for most decisions. Use EDT in conjunction with other models such as the CRI, PATH, and CRITFC tools. Take advantage of the strengths of each model system and appreciate the different perspectives afforded by each.” The ISAB wholeheartedly endorses this recommendation. Results from a model, given knowledge of its assumptions and quality of data used, cannot decrease the information available to a decision-maker.

Conclusions

Conclusion 1: *None of the models presently in use in the Columbia Basin is complete enough to serve as the sole decision support tool for the region.*

The models available to support decisions in the Columbia River Basin serve different functions and all have strengths and weaknesses. The models differ in the problems they are attempting to address, the analytical approaches to the problems, the assumptions underlying each of the approaches, the quantity and quality of the available data, and the rigor with which they deal with the complex life cycles and habitats of the species.

PATH scores high for its attempt to operate in a decision context that was explicit about uncertainties, and for attempting to formally quantify uncertainty in a reasonably sophisticated way. Where PATH appeared weak was in the very narrow range of factors that it took into consideration, and in the tortuous model structure that posed an obstacle to diagnosis of model behavior. Notwithstanding a large amount of good work, PATH was vulnerable to the criticism that it had not answered the question asked of it, and that it was trying to answer policy-sensitive questions that had not been asked of it. It was not entirely clear, however, who was in charge of PATH, or to whom PATH was supposed to answer. Furthermore, because of its "consensus" structure, PATH was notoriously slow in operation, and it generated unwieldy volumes of reports.

CRI scores high for clarity and tractability of model structure, but it lacks statistical treatment to quantify uncertainty. Although CRI encompasses a broader range of factors than the original PATH models, it still appears deficient in necessary detail for habitat variables and spatial and temporal structure. Both CRI and PATH rely on derived quantities in place of actual data, in ways that confound a proper uncertainty analysis. CRI clearly is investing heavily in attempts to remedy these deficiencies.

EDT scores very high marks for comprehensiveness of factors taken into account, and for spatial and temporal detail in the data it uses. It is not yet clear whether EDT is sufficiently rigorous about maintaining the separation between actual measurements and derived quantities, or in quantifying the uncertainty of the derived quantities. The predictive modeling component of EDT is essentially an expert system. The process of eliciting expert judgment may include obtaining opinion about certainty, but that too is expert judgment, rather than a statistical comparison to actual measurements. So it looks as if EDT does not yet include a satisfactory treatment of uncertainty.

ICBEMP-BBN like EDT gets high marks for comprehensiveness and for spatial and temporal detail. ICBEMP-BBN went one important step beyond EDT by formally eliciting expert judgment about uncertainty and propagating this uncertainty through the model predictions. ICBEMP-BBN was constructed as a Bayesian Belief Network, which confers the advantage of explicit representation of uncertainty as probabilities. The Bayesian statistical framework lends itself to value-of-information calculations that can help guide decisions about future monitoring, ground truthing, or experimental interventions to help resolve critical uncertainties. ICBEMP-BBN did not avail itself of this potential, but it is an attractive option that should be considered as EDT evolves toward calibration and validation.

Both ICBEMP-BBN and CRI seemed to enjoy very successful communication with their respective decision-makers. In both cases, scientists and decision-makers were part of the same organization. The decision questions that the modeling efforts were intended to inform were well-defined in advance of the modeling project, the models were directed at those questions, and the decision-makers seemed not to experience difficulty in understanding and using the model results.

Among the Columbia River basin salmon modeling efforts, the PATH experimental management (PATH-EM) report represents the most substantive attempt, to date, to provide an analysis of the prospects for actual Adaptive Management. The analysis described specific experiments and provided a preliminary assessment of the types of information that the experiments would provide, and how much time they would require for completion. There seems to be a temptation, in many quarters, to co-opt the term “adaptive management” merely to put a positive spin on vague management plans. Thus, it is important that this kind of technical analysis of adaptive management resume as an ongoing enterprise connected to actual decision making in the Basin.

Conclusion 2: The models are best at ranking the expected effects of management alternatives.

The general conclusions of the models are often in close agreement with respect to the predicted rank of management alternatives when addressing similar problems and using the same data sets. The models, however, are not good at giving absolute numerical predictions and they do a poor job of accurately estimating what the policy-makers may need most, namely, a credible scientific analysis of the probability (feasibility) that some measurable degree of salmon recovery will be achieved with any particular management action.

Scientists can help environmental decision processes to cope better with uncertainty by explicitly quantifying the relevant uncertainty. Statements of the respective probabilities of alternative scenarios are a natural way to communicate uncertainty when the decision is essentially placing a bet about which scenario actually will materialize.

Conclusion 3: All the modeling efforts are severely constrained by lack of data.

Modeling controversies in the salmon arena have largely been an unproductive distraction from the real scientific problem of inadequacy of the available data for addressing many of the important management questions. Some of the debate that now centers on competing models could be resolved with the right data. The present paucity of data creates more scope for alternative assumptions in the models. Sophisticated, responsible modeling takes all the plausible alternative assumptions into account with weighting according to their respective concordance with the data that are available. This need not lead to "modeling wars."

Where scientific leadership and institutional innovation needs to be exercised is in the prioritization, design, and implementation of large-scale monitoring linked to management experiments. There is at present no institutional center of authority for addressing the prioritization; design and coordination issues for large-scale monitoring linked to management experiments.

Conclusion 4: *Decision-makers would be well served by drawing on all the available analytical tools.*

Decision-makers would benefit by focusing on areas of consensus among the models or the weight of evidence provided collectively by the models. Areas of disagreement among the models may pinpoint uncertainties that require further investigation. In considering how results of models make their way into the decision-making process, it is helpful to recall the roles of models. They provide ways of organizing and communicating information, generating hypotheses, and pin pointing the crucial gaps in information. The modeling efforts are not ends in themselves; they are not final, definitive answers, but rather they are ongoing processes for continuously increasing knowledge.

Conclusion 5: Effective communication between decision-makers and scientists is essential if scientific results are to play an integral role in the decision-making process.

Decision-makers need to understand what science is able to accomplish relative to a particular problem, given data limitations, inherent environmental variability, uncertainty, and so forth. Decision-makers need to frame questions that are appropriate for science to address and to make their needs clear to scientists. To maintain the trust and support of scientists and the credibility of the decision-making process, decision-makers should clearly explain the basis of a decision to scientists and the public.

To prevent scientific debates over the models from encumbering the decision process, it is crucial for decision-makers to understand both the capabilities and limitations of models. Without an understanding of model capabilities and limitations there is the danger that decision-makers will develop unrealistic expectations of the models. Models constitute a way of organizing and communicating information. They provide a systematic way of predicting outcomes of management interventions, identifying what cannot be reliably predicted and quantifying uncertainty. Models can generate useful hypotheses and identify crucial gaps in knowledge. These functions provide a valuable guide for setting priorities for data collection and suggesting new experiments to resolve critical uncertainties.

Scientists need to comprehend the needs of the decision-maker and understand that, although science plays a critical role in formulating decisions, decision-makers also must weigh the social, cultural, and legal implications of a pending decision. Scientists need to inform decision-makers of the full suite of management alternatives that address a particular question or problem and the uncertainty associated with each alternative. The nature and extent of the uncertainties have to be explained in language that is meaningful to the decision-maker. This is especially important when the uncertainty is large, as is common in salmon management problems. If decision-makers are not adequately informed, their expectations are not met, or they are faced with uncertainty that is a consequence of strong disagreement among scientists over appropriate courses of action for recovery, the decision-making process could be driven largely by social, legal, and economic factors, to the possible exclusion of much of the available science, or a decision will be deferred pending further research.

Recommendations

Recommendation 1: At present, the region should fund specific groups to undertake specific modeling projects, not large collaborative modeling efforts.

Achieving consensus among scientists with widely divergent views has proven to be difficult in large, collaborative modeling projects. These large modeling efforts may not be necessary because the kinds of models that are actually justifiable are not really that complicated, given the amount of data that are available. Small groups of researchers should be adequate to pursue development of the models. And the coherence of vision of a small group may encourage clarity in the resulting model. That coherence is very difficult to achieve as the group gets large. The correct way to proceed with modeling needs is to fund specific groups to undertake specific modeling projects.

There would be merit to funding several groups to pursue modeling questions. There would even be merit to a degree of overlap, so that the same data sets might be analyzed from somewhat different technical perspectives, which would encourage the evolution of scientific insights. The actual dollar cost of modeling, as a fraction of the overall salmon recovery budget, has been very small, so this is not the place to look for cost cutting.

Overall, the region needs modeling efforts that collectively combine the best features of all the models we have reviewed. Features of ICBEMP-BBN and EDT could be used to formulate working hypotheses concerning, for example, causes of salmonid declines and potential effectiveness of management interventions. Features of ICBEMP-BBN could be used to communicate the uncertainty of the working hypotheses. Features of CRI could be used to test hypotheses wherever data were available. Features of PATH could be used to quantify the uncertainty of the tests of the hypotheses and to place recommendations for management in a risk assessment context. Furthermore, CRI might serve as an inspiration for clarity, rigor, and openness.

Recommendation 2: The region should develop and implement a region-wide monitoring and evaluation program.

The belief that Columbia River salmon management constitutes an expensive failure of "salmon science" is a vastly oversimplified perception. Most of the money spent on salmon recovery has been spent on management actions, not on science. The science that was conducted has contributed substantial knowledge that is relevant to salmon recovery, but this knowledge has not always found its way into the decision-making process. One of the critical shortcomings that hamper salmon science is the shortage of high quality data. There are many important questions in salmon management that are going unanswered for lack of data, and some of the debate that now centers on competing models could be resolved with the right data. Where scientific leadership and institutional innovation needs to be exercised is in the prioritization, design, and implementation of large-scale monitoring linked to management experiments.

Recommendation 3: Scientific results should be published in the peer-reviewed literature.

One pathway toward resolution of scientific disagreement is through publication in the peer-reviewed scientific literature, and provision of access to model code and to data files allowing independent verification. Data access should include access to the original primary data and metadata. If there is not access to the primary data, derived quantities, when treated as if they were data, may carry error that escapes scrutiny. Publication in the scientific literature establishes credibility for the use of science in Columbia Basin decision-making. A greater reliance on the mechanisms of normal scientific discourse might also reduce some of the contentiousness that has characterized the history of scientific debate over key issues in Columbia Basin salmon management.

Recommendation 4: The region should develop effective ways to improve communication between scientists and decision-makers.

To facilitate communication between scientists and managers a formal institutional mechanism for synthesizing scientific results and clarifying the interpretation of the various salmon models for the policy makers should be developed.
If a modeling effort is motivated by a desire to contribute to a particular decision, it is especially helpful to initially invest in enough communication to ensure that the model really is addressing the right question. Scientists can work with decision-makers in crafting decision rules that get formalized before the analysis is undertaken. Decision rules define what measurements will be made, what statistical operations will be performed on the data, and what threshold magnitudes of estimated quantities at specified levels of certainty will serve as criteria for the decision. Such specifications help remove ambiguity from the way science is used in the decision process. Committing to these specifications in advance helps dispel suspicions that the analysis may be manipulated to achieve a particular outcome. If institutional trust does not embrace a particular model, the need to establish credibility can stand in the way of getting a model's results considered in the course of a decision.