Klamath River Fall Chinook Salmon Assessment Approach and Methods Review

CIE Review

By

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Executive Summary

In this report the stock assessment and management system for Klamath River fall chinook salmon was reviewed. The review consisted of an examination of a number of reports, memoranda and published papers describing, in varying degrees of detail, the procedures currently in use.

The Klamath management system is as intensive and detailed as any on the Pacific coast and is certainly consistent with current practice for chinook salmon populations. In reviewing the system's components I find a need for the testing of assumptions of each procedure, and a formal inclusion of variability into the procedure that would ultimately lead to estimates of uncertainty in the primary assessment outputs, the annual forecasts of catch and river escapements. The key recommendations by task are:

1) *River assessment*: Conduct a one-time review of the complete spawning stock and freshwater fishery assessment program to ensure that the resulting estimates, which are the basis of much of the management advice, are unbiased and sufficiently precise. Although much detail was provided on ageing, I could not readily evaluate the creel or escapement programs with the information provided.
2) *Cohort reconstruction*: Sensitivity analysis or simulation could be used to determine how the final abundances are affected by uncertainty in input river abundances and catch data.
3) *Forecasting ocean abundance*: I recommend that more statistical work be done with the forecast models to determine the adequacy of the model and to generate estimates of uncertainty in the forecasts.
4) *Forecasts of Catches and Escapements*: Sufficient data are now available to test the underlying assumptions of KOHM, especially with respect to the linear relations between fishing seasons and effort, and effort and catch, and the independence of those relations for areas, months, ages and gear types. Thought should be given to trying to either project the uncertainty in the model inputs through the outputs, or to using the retrospective information to approximate the uncertainty in future forecasts.

Fall chinook are usually quite unpredictable in their abundances, and this natural variability, coupled with the uncertainty associated with typical fishery management systems, suggests that the use of a risk-based approach to management is warranted. An important first step in this process is the incorporation of uncertainty in the management advice generated from the Klamath River chinook assessment program.

Introduction

The Klamath River, located in northern California and southern Oregon, supports a large fall chinook salmon population that is significant for local aboriginal peoples, and contributes to important river and ocean sport fisheries and the commercial troll fishery off California and Oregon. The management of this population is achieved through an intensive information system that predicts river and ocean abundance and impacts of fisheries on abundance. The purpose of this review is to consider whether the assessment system is the best available science for the purpose.

Based on the CIE terms of reference, the review was organized to cover the 4 main components of the Klamath River assessment process as listed in the statement of work:

The KRFC annual assessment consists of four principal sub-assessments: (1) estimation of the previous year's river returns, (2) cohort reconstruction of the natural and hatchery stock components based on coded-wire tag recoveries, (3) forecast of the current year's ocean abundance and proportion of natural fish, and (4) forecast of the current year's fishery harvests and spawner escapement under PFMC-proposed management measures.

The review of each component was organized to address the following questions provided by CIE:

1. *Evaluate the approach: determine if it is adequate and appropriate for the assessment.*
2. *Evaluate the data: determine if it is adequate and appropriate for the assessment.*
3. *Evaluate the methods and assumptions: determine if they are adequate and appropriate for the assessment.*
4. *Evaluate the uncertainty: determine the primary sources of uncertainty in the assessment.*
5. *Determine whether the data, approach and methods constitute the best available science for the intended purpose.*

Task 1: Estimation of the previous year's river returns.

The review of the inriver estimation of abundance is based on the documentation provided in the KRTAT (2006a) document entitled "Klamath River Fall Chinook Age-Specific Escapement River Harvest and Run Size Estimates, 2005 Run". KRTAT (2006a) is a relatively brief description of what is an apparently intensive escapement estimation program, and thus makes it difficult to provide a detailed review of the assessment process.

River run size is an important input to the management system as the "Natural Area Spawners" is a key performance measure, and the abundances of the younger ages are used as forecasting variables for predicting ocean abundances of the older ages of each cohort. The need for accurate and precise estimates of age-specific abundance are especially critical for small cohorts, as these will have a considerable influence on predictions of ocean abundance in the following year, potentially leading to the imposition of conservation actions if abundances are forecast to fall below critical levels.

The estimation of total natural spawners.

KRTAT (2006a) provides a brief summary of a suite of methods used to estimate the total number of natural spawners. Presumably the methods used in each part of the basin have evolved over time, and have been deemed appropriate given physical/logistical considerations, the expected number of spawners in each area, and resource limitations.

Spawner estimates.

In general, estimation programs on valued spawning populations are accompanied by tests for bias and imprecision to satisfy concerns that these sources of error are not dominating the results. I assume a comprehensive, documented analysis has not been conducted, as it has not been made available to CIE. In the absence of specific details of the programs, these are some considerations for such a review.

1. Peak Redd counts. Are these counts accurate and precise, and is the use of a 1:1 sex ratio appropriate for scaling the redd counts appropriate? I'm certain these can be evaluated with data from other calibration studies, if Klamath-specific data are not available.
2. Peterson estimates. There are a variety of diagnostic tests available for capture-recapture programs. In general, most sources of bias in tagging programs tend to lead to overestimates of abundance because of tag shedding, differential mortality of tagged fish, and non-random tagging or recovery. In addition, sex-specific differences in carcass recovery can lead to biased estimates, and can be checked by making sex-specific population estimates. Because male spawners tend to wander after spawning (and jacks may not have affinity for any specific redd or spawning area), sometimes far fewer males carcasses are recovered than females. The situation is further compounded if there are sex-specific age structure differences in the spawning population.

Handling and tagging adult fish is always a source of stress, and can lead to mortality, or unusual behaviour that renders the tags less vulnerable to recapture compared to untagged fish. This situation may be exacerbated when high water temperatures and low flows are involved. Further, the non-random recovery of carcasses and/or tags can cause biased estimates. These issues can be evaluated by stratifying the recovery data to estimate changes in the rate of recovery of tags over time (which can be an estimate of stream life), as well as spatial stratification of the data to determine if the tags are well distributed in the stream.

3. Carcass recovery. Non-random recovery and sampling of carcasses will affect both the Peterson population estimates, and the relative age distribution that is ultimately applied to the population estimates to generate the age-specific run sizes. If large fish are more readily found and recovered than small ones, or if females are more common than males, then the age data used for cohort reconstruction could be biased. It should be possible to evaluate these sources of bias from locations where age distributions are known (such as streams where weir sampling is conducted), or by evaluating age and sex specific recovery rates of tagged fish.

Age Determinations

The information provided in KRTAT (2006a) suggests that considerable effort has been applied in ensuring sufficient scales are read from various components of the run, and the accuracy of scale readings is evaluated through the use of the known-age CWT fish. The use of the inverted validation matrix to correct misread scales is critical in years when there is a large discrepancy in cohort abundance so that low rates of misclassification of large cohorts can have a large impact on adjacent small ones. This is evidenced in KRTAT (2006a) for Klamath Carcass data that show that the abundance of age-2 fish would have been substantially overestimated because of ageing errors, unless a correction had been performed.

In River Harvest Component

Little information is provided to evaluate the accuracy and precision of the creel census and catch reporting for the recreational and tribal fisheries, so it is difficult to comment on the adequacy of these programs. It is apparent from Table 1 of KRTAT (2006a) that the recreational fishery on jack salmon is apparently significant as it accounted for nearly half of the total jack estimate for the system in 2005. Given the importance of the age-2 estimate for cohort forecasting, it is worth asking whether it is realistic for the sports fishery to capture nearly half the system jacks, yet land (with bag limits) only 2.5% of the adult population. One interpretation of this result is that the number of age-2 spawners in the system has been overestimated, or the creel census is biased in some fashion. No information on the origins of the hook and net mortality rates has been provided, but at first glance they would seem to be low for a situation where, in recent years, disease problems have been a significant source of mortality. The stress associated with capture and release may be more important in these circumstances than in years of more benign environmental conditions.

The above discussion is summarized in response to the CIE Terms of Reference Questions:

1. *Evaluate the approach*: The approach to estimating the abundance and age structure of the run is adequate and appropriate.

2. *Evaluate the data*: CIE reviewers have only been provided detailed information (i.e., raw data) for the ageing component of the assessment. Over 20% of the total run was sampled for ageing structures- this is a very high rate of sampling and certainly appears adequate. Details about the raw abundance data used to arrive at the subcomponents of the abundance estimate have not been provided and this question is difficult to evaluate.

3. *Evaluate the methods and assumptions*. The methods used to estimate the abundance of salmon in the river are among those in standard practice. Each method has a series of assumptions and if they are violated can result in biased estimates. No information to evaluate those assumptions is provided in the available documentation, and it is suggested that a review of the methods be conducted to ensure they are as unbiased as possible.

   The application of the corrected age distributions to estimate cohort abundance is contingent on the assumption that the live fish or carcasses that are sampled are representative of the actual run. This assumption should be evaluated.

4. *Evaluate the uncertainty:* Uncertainty in this stage of the process could have considerable influence on the results of the fishery model. Of particular importance is the age-2 estimate of abundance which typically constitutes only 5% of the run, but is a significant input in the forecast models. While the complexities of the estimation process makes deriving an uncertainty statistic for the age-specific abundances difficult, it is important to be aware of potential sources of bias in the estimation procedure. Based on KRTAT (2006a), some questions regarding primary sources of uncertainty are:

   a. Is the sampling rate of age-2 and older fish in the river recovery programs proportional to their abundance? This is of particular concern for carcass recovery.
   b. Are the capture-recapture estimates unbiased in relation to sex and age?
   c. Can the creel census estimate of age-2 catch be reconciled with the in-river and total age-2 abundance?

5. *Determine whether this constitutes the best available science for the intended purposes.* As noted by Mohr (2006a), the Klamath River fall chinook sampling program is comprehensive and I find that it is consistent with practice in many other jurisdictions. However, the documentation that CIE was provided does not indicate whether potential biases that are well-known in spawning ground assessments have been evaluated here, and what their impacts might be. Given the

importance of age-specific cohort estimates it would seem appropriate to conduct and publish a one-time review of each component of the spawner assessment to provide assurances that the final estimates are adequate, and to indicate any uncertainties that might remain.

One issue that may be important (but is difficult to determine from the data available) is whether sex-specific differences in age at maturity and catchability (or rate of carcass recovery) interact to influence the estimates of abundance of the younger fish in the spawning population. No reference is made to sex-based analyses in any step of the Klamath assessment process.

Task 2: Cohort Reconstruction

This step is the reconstruction of past ocean abundances from escapement and catch data. Goldwasser et al. (2001) and Mohr (2006b) were the primary documents used for this section.

1. *Evaluate the approach:* Cohort reconstruction is required to generate a historical database of abundances and exploitation patterns for the forward forecasting harvest model. The approach used for Klamath River fall chinook (recursive cohort analysis) is similar to that of other management agencies along the Pacific coast. It is essentially an accounting exercise, relying on input abundance data and externally derived parameters; it is not conducive to generating estimates of uncertainty for model predictions, nor testing for the appropriateness of the approach. The main alternative approach, that of statistical catch-at-age modeling, estimates parameters from model data and can account for uncertainty and model fit. This approach has been used for chinook salmon (Savereide and Quinn 2004). A significant challenge for statistical catch at age modeling for Klamath chinook would be the requirement to model the 7 different management units and the fishing effort and catchability in each unit. Ultimately the effort may not be worth the benefit.

2. *Evaluate the data:* The primary inputs for the cohort reconstructions are the age-specific river abundances (which were reviewed as *Task 1*), and the CWT recoveries from the fisheries. The overall rate of CWT marking from the 2 hatcheries (Mohr 2006b) is typical of production hatcheries, and the sampling rate of the catch is appropriate (~20%), though no details are provided on the representativeness of the sampling program. It is assumed that the sampling program has remained relatively consistent over the time series. The breakout of the CWT data by year, age, release type and area/gear can result in relatively few CWTs per strata, especially in years when abundance is low (Goldwasser et al. 2001, Tables 4 to 10). A quick assessment of the total number of CWT's recovered (Goldwasser et al. 2001, Table 6) relative to the total catch by year suggests that the ratio of catch to recovered CWT's is about 100:1 to 200:1, and the ratio of estimated pre-season abundances to recovered CWTs is usually much

greater than that, meaning that sampling variability in the CWT's could play a significant role in the final estimates. Nonetheless, the data appear to be adequate and appropriate for the task.

3. *Evaluate the methods:* The cohort reconstruction model used for Klamath River fall chinook salmon is typical of other cohort models used for chinook salmon on the Pacific coast. Each cohort or brood is reconstructed based on the estimated numbers of fish in the escapement, and a backwards (in time) reconstruction of earlier abundances inflated by age-specific estimates of the catch, fishing related non-catch mortality, and natural mortality. Non-catch fishing mortality, natural mortality, and size-based vulnerability are input parameters derived from other analyses.

   An important assumption of this method is that the input parameters are fixed in time and - in some cases - space. Some explicit allowance for time trends is included in the fishery regulations and non-catch mortality associated with mooching. Trends or variation in body size would affect the proportion legal parameter, and could be assessed in year-specific analysis similar to those presented in Goldwasser et al. (2001). Variation in ocean mortality is usually assumed constant but could vary with coastal productivity or other factors. Only in the statistical catch-at-age approach can trends in parameters be evaluated in the model fitting process. In cases where parameters are fixed (e.g., mortality rates), real variability in those rates turns into variation in calculated quantities (e.g., contact rates).

   Natural mortality is distributed evenly across months based on assumed annual rates. The assumption could be contested by those that feel that mortality is likely higher during the winter months. Lower summer mortality rates will tend to slightly lower reconstructed abundances during the fishing season but that will make little difference to year over year changes. The natural mortality rates used are similar to those used for other populations although there is little justification for those values in Mohr (2006b) or the in cited source (KRTT 1986).

4. *Evaluate the uncertainty.* The reconstruction algorithm uses two main data sources (CWT recoveries, and terminal (river) abundance, which is a composite estimate), and a suite of input parameters to correct for sampling effort, and mortality rates (natural and fishery-related). None of the documentation provides any evidence for the importance of parameter uncertainty on the model's final outputs.

   Thus it is difficult to determine the primary sources of uncertainty as there are many inputs that will all contribute to the uncertainty in the age-specific ocean abundances. No estimates of the uncertainty in age-specific river abundances have apparently been calculated, but this is likely significant (see *Task 1* review). It should be possible to derive standard errors for the area-wide monthly catch estimates based on the sampling intensity. The significance of annual and long-term trends in natural mortality should also be considered.

Each source of uncertainty can be evaluated in a standard sensitivity analysis to prioritize those that have the greatest influence on model results. Such an analysis can be used to direct efforts to analyze and potentially reduce bias and precision in the cohort reconstructions.

5. *Is this the best available science?* The approach used is similar to that used in the Pacific Salmon Commission model and those used for Columbia River chinook salmon. The most advanced approach to this type of analysis is statistical or Bayesian catch-age modeling. However, these are not in common use for salmon cohort analysis, and the additional effort may not yield significant practical, benefits. At a minimum, additional analyses to identify and quantify the uncertainty in the cohort reconstructions would be a significant step in improving the scientific underpinnings to this part of the assessment process.

   In many jurisdictions, genetic stock identification (GSI) is being used to allocate catch to populations. GSI reduces reliance on CWT data and the assumption that hatchery- and wild-origin fish have the same distribution and catchability. Sampling is not limited by the presence of CWT fish, though the analytical costs can be restrictive (and an adequate baseline is required for its use). Information on the catches and distributions of other populations in the fishery areas also become available with this technique.

Task 3: Forecasts of Current Year's Ocean Abundance and Proportion Natural.

Sibling models are used to predict the abundance of fish in the ocean as a function of the age-specific abundances in the river population the year before. KRTAT (2006b) provides a brief description of the methods and data, and some additional analysis is found in Prager and Mohr (2001).

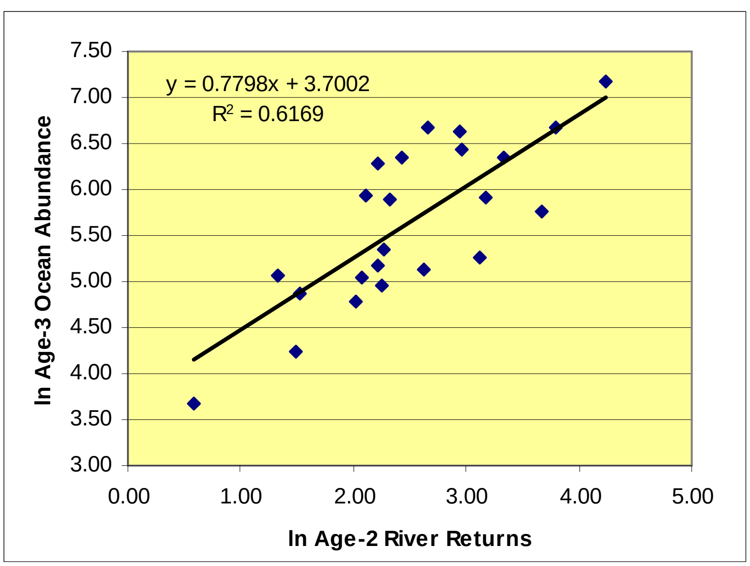
1. *Evaluate the approach:* Sibling models, where the abundance of a single age group is used to predict the abundance of the next age group of the same cohort, is used as a forecasting tool for Klamath fall chinook. Sibling models are a commonly used tool for forecasting salmon abundances along the Pacific coast. This approach requires the development of a predictive relation based on past data. For Klamath chinook, the predictive relation is between the abundance of a single age class in the river run, and the forecast variable, which is the estimated ocean abundance of the next age group of the same cohort in the ocean the following summer. Sibling models are most useful when the age at maturity schedule is relatively consistent across cohorts and over time. The case where long-term changes in the age at maturity (presumably caused by changes in

growing conditions in the ocean) affects sibling models has been evaluated by Holt and Peterman (2004).

2. *Evaluate the data:* The development of the data used in the forecast models have been reviewed in Tasks 1 and 2. Uncertainty in the abundances used in the models will have different effects on the forecasts. In the case of ocean abundance (Y-axis), uncertainty will increase the uncertainty in the forecasts, but will not bias the results. However, uncertainty in the river returns by age (the X axis) can potentially bias the forecasts by the well-known errors-in-variables problem. Errors in the X-axis variable can depress the slope of the regression, but the extent of the bias depends on the ratio of the variance (not SD) of the measurement error relative to the variance in the X-axis variable (Snedecor and Cochran 1989). Given the wide range in the river abundance data the errors in variables problem may not be a significant factor in the Klamath case, but may be worth investigating if uncertainty estimates for age-specific river abundances can be developed.

3. *Evaluate the methods:* Specification of the appropriate model and the testing of the model with diagnostics are important parts of establishing a predictive relation to generate forecasts and their associated uncertainty. I was surprised by the use of a simple ratio estimator when there is clearly heteroscedasticity in the data. Most published sibling regression models use log-log models to stabilize the variance, reduce the dominance of very large cohorts on the model fit, and allow for non-linearities in the data.

   As an example, I plotted the data for the age 2-3 regression in Figure 1 of KRTAT 2006b in log space:



The prediction of the age 3 abundance from the model for 2006 is about 77K, and could be increased by about 15% by the $\sigma^2/2$ correction normally used for log-log regressions (Beauchamp and Olson 1973). Uncertainty about this prediction can easily be calculated using standard means; I have not done this, but confidence intervals of at least +/- 50% are likely based on the magnitude of the residuals ($\sigma = 0.5$).

The substantial difference between the results of this commonly used approach and the ratio estimator employed in the Klamath River analysis (KRTAT 2006b) highlight 2 points: (1) forecasts are always uncertain and a wide range of values are not unlikely given the data, and (2) model selection is an important component of that uncertainty. Both of these should be addressed in a review of the assumptions of the sibling model approach.

Finally, successful sibling modeling requires a stationary age at maturity schedule, and this can be evaluated by plotting time series of the regression residuals and conducting autocorrelation analyses for serial independence. A quick examination of the data does suggest time trends in the age at maturity. It might also be worth searching for correlations across ages (i.e., residuals from the 3 siblings) by aligning by brood year and calendar year to see if the uncertainty in age-specific estimates covaries among age groups or years.

4. *Evaluate the uncertainty:* Uncertainty in the forecasts is going to be significant given the scatter in the regression plots (Fig 1 of KRTAT 2006b). This is typical. A recent forecast document for Fraser River sockeye salmon provides additional examples: http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2006/RES2006_060_e.pdf . This document also provides examples of dealing with diverse sources of information and competing forecast models.

5. *Is this the best available science?* It appears there is some room for improvement in this step of the assessment process. A review of the models used for forecasting is needed as well as additional statistical analysis. Estimates of the uncertainty in forecast abundances are straightforward to calculate and should be included. A larger challenge is finding the best format for presenting uncertainty information, and assisting managers in finding ways to use it for their decision making. An example is provided in the Prager and Mohr (2001) analysis.

Task 4: Klamath Ocean Harvest Model

This step uses historical abundance, effort and catch data to predict the impacts of management regimes on ocean and river catches and escapements. The primary reports that were reviewed were Goldwasser et al. (2001) and Mohr (2006 c,d,e), as well as Prager and Mohr (2001).

1. *Evaluate the approach:* The KOHM is a detailed model that uses historical catch and effort data combined with reconstructed abundances to forecast the impact of a proposed fishery management regime on current stock abundance. The approach is empirical, relying on historical data to predict future events. There are no state-dependent functions (e.g., effort in relation to previous catches or forecasts, etc.) that provide a more mechanistic perspective to the variations in effort and catches.

   The approach is contingent on stationarity in the key processes. The model predictions are largely based on the average ratios of effort/days open and contacts/effort by month, year, and area. It is assumed that the distribution of the stock is consistent (or consistently random) across years, as is catchability. The model also assumes that the deployment of effort across areas in relation to regulations is consistent across years. As noted in the recent documentation, when these relations appear to break down, an ad-hoc approach is being used to adjust the formulation of the model to make the outputs more consistent with recent experience. This has the potential to get out of hand as these "fudge factors" accumulate within the model structure. So-called "unusual" events will be more likely to occur as more years of data accumulate, and may also be more likely if increased environmental variability (e.g., that associated with climate change) continues.

   Nonetheless, given the richness of the catch and effort database, the concept of using an empirical approach is reasonable.

2. *Evaluate the data.* The main sources of data are the cohort reconstructions reviewed in Task 3, and the regulation and effort database. I assume the regulation database is accurate.

   The commercial effort database consists of estimates of effort derived from the total landed catch and the catch and effort data for sampled boats. It uses the ratio of the mean catch and effort for the sampled boats of that port, and is thus based on an assumed linear relation between effort and catch (through the origin) with a symmetrically distributed error structure. No analyses of these data are indicated, but it would appear that given the extent of the database, more detailed work is possible. Catch per trip, trip length (and thus effort) can vary with a number of factors, including catch rate, sailing time, regulations, vessel size, market factors etc. and there may be merit in exploring these data further. At a minimum there are sufficient data to validate the use of the ratio estimator (equation 2 of Goldwasser et al., 2001) over equation 1. While it is true that equation (2) does avoid the issue of non-random sampling of boats and thus trip lengths, it does assume that large and small boats have the same average catch rate (catch/day), which needs to be tested.

   Because the estimates of effort are based on landings (equation 2 of Goldwasser et al. 2001), rather than logbooks or interviews, and the landings also form the basis of the contact rate estimates, (the contact rates are based on the CWT recoveries from sampled boats) there is some potential for covariation in these presumed independent data sources if the sampling is non-random with respect to catchability or catch/day. Some effort to evaluate this appears warranted.

Details of the sport fishery effort estimation procedure are not provided and the adequacy of these data cannot be evaluated.

3. *Evaluate the methods.* The core of the model are 2 sets of calibrations—the conversion of regulations to predictions of effort, and the relation between effort and contact rate, by gear, area and month. The contact rate is based on the total ocean abundance as area-based predictions of abundance are unknown.

   Simple ratio estimators are used for the effort and contact rate predictions, although a formal justification for this approach has not been provided. Non-linear relations between effort and days open seem highly probable based on a quick visual examination of the data in Mohr (2006e) and would be consistent with a behaviour of maximizing fishing time in months in which time restrictions occur. A non-linear relation in the form of a saturation curve could have a substantial influence on the regulations on fishing mortality.

   Similarly, contact rate (which is similar to catchability) is assumed to be proportional to effort across the range of efforts and fish abundance, as well as constant over time. Non-linear relations between catch and effort have been described in many fisheries, as have trends in catchability associated with technological developments and fleet behaviours.

   Finally, there are a suite of input parameters (Table 2 of Mohr 2006c) that are based on various supporting analysis and appear to represent the best available information.

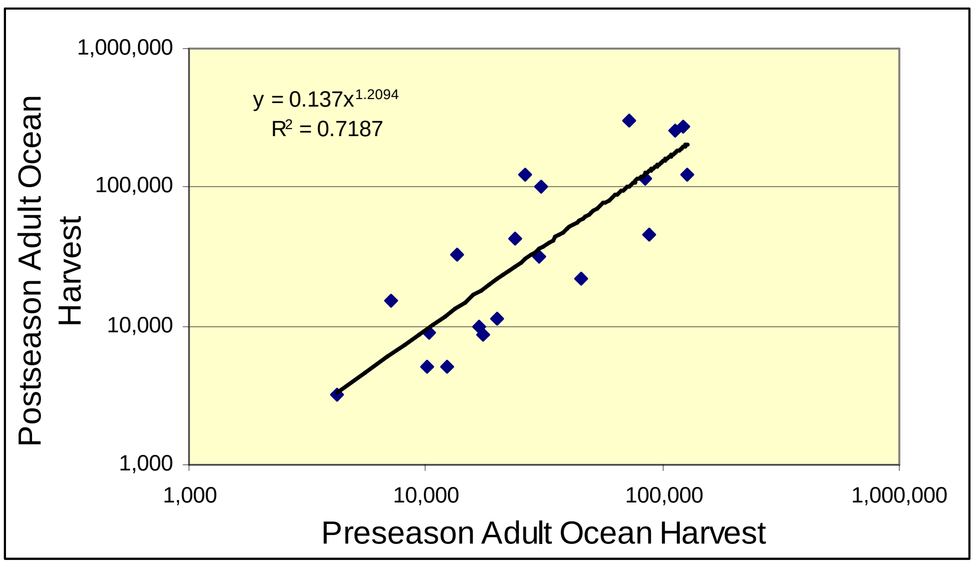
   I conclude that the methods are generally suitable as long as the key assumptions of the model are satisfied. These include the linearity in the predictive relations and the stationarity in parameters, which can be easily tested with the data available.

4. *Evaluate the uncertainty.* There is no explicit provision for uncertainty analysis in KOHM. Yet, there is substantial uncertainty in each of the inputs to the analysis- the prediction of ocean abundance from sibling models, and the prediction of contact rates from effort-regulation relations. That uncertainty propagates and compounds through the model.

   The variability in the effort and contact rate predictions are very large, and if explicitly incorporated in the model could account for some of the wide uncertainty about the predicted harvest. The variability resulting from the calibration data might be mitigated if the uncertainty around the individual regressions is indeed random and independent so that the accumulation of catch over many area-month-age-fleet strata nullifies some of the uncertainty associated with individual strata.

Further analysis of the data would be useful to help understand the sources of variation in the data. For example, correlations of residuals across gear types within areas might be an indicator of interannual variation in local abundance. Correlations across all areas and gears might be indicative of errors in the estimation of abundance, correlations across ages within strata might reflect changes in catchability or fleet behaviour. Is the association between effort and days open per month a function of the contact rate for that month or the previous month? These analyses may reveal structure in the data that can be taken advantage of to reduce forecast uncertainty, or at least understand its sources in terms of fleet and fish behaviour. Similarly, an analysis of time trends in the residuals from the ratio estimators can provide insight into changes in fishing patterns, fish distribution or other factors that cause uncertainty in model results.

The ultimate measure of the uncertainty is the difference between the key model predictions and the actual outcomes. In the following figure I plot all the data for predicted and observed ocean catches from KRTAT (2006b, Table 3) with the axes in logarithmic form:



This figure shows that although the general magnitude of the harvests is predicted quite well, there is still substantial uncertainty. That uncertainty is proportional to the prediction (thus the uniform residuals on the log scale), and appears to be in the order of at least +/- 100%. The constant error on the log scale is consistent with the multiplicative propagation of error through the model structure. The exponent is >1, which implies the model under-predicts at high abundances. This point has been identified for the early years of the time series for model structure/data reasons, and for the recent years because of changes in effort distribution. There are also some significant over-predictions at high abundances as well. The figure clearly shows that the proportional errors are similar at high or low abundances.

The relative contribution of the uncertainty in the model components on the ultimate prediction error can be assessed by a process similar to that used by Prager and Mohr (2001) - for a given set of management rules, the model can be run with a fixed set of abundance and effort/contact data (considered real, perhaps the historic time series), and then rerun with one of the inputs changed to a stochastic variable with a realistic error term based on the data. By conducting this analysis with each major input data source (and its associated uncertainty) a rough guide to the major contributors to forecasting error is possible.

It might also be worth examining the likelihood that proposed changes in the fisheries management regime will have the desired effect given the uncertainty in the effort and catch predictions. If effort and contact rates are as variable as suggested by the data, then there is likely considerable uncertainty in whether management actions consisting of time-area closures/openings will result in the effects predicted by the mean responses. Again it is worth evaluating whether the errors (residuals) in the gear-month-area strata are independent across strata.

5. *Is this the best available science?*

   A key feature of modern fisheries assessment advice is the provision of uncertainty around outputs from models used to forecast the impacts of regulatory alternatives. While the basis of KOHM is sound, its inability to provide forecast bounds for the key outputs (catch and escapement) is a shortcoming that needs to be addressed before the model can be considered “the best available science”.

   There are many examples of non-linear relations in effort and catchability relations in the fisheries literature (and textbooks), and an analysis of alternative model forms to support (or refute) the ratio estimators used in KOHM are needed. Sensitivity analysis would be useful to determine the significance of the supporting inputs (mainly non-catch sources of mortality), to determine whether uncertainty in these outputs are really significant.

   Finally, the ultimate goal of KOHM is effective effort regulation to achieve management goals in terms of catch and escapement. There should be sufficient information available to look retrospectively at whether annual changes in regulations have had the desired effect in terms of fishing mortality, and to quantify the magnitude of these differences (sometimes called implementation error) that has occurred in the past. Such information is of value to managers so they can evaluate the potential for their regulatory changes to not produce the desired or predicted outcomes.

Summary and Recommendations

The Klamath River assessment is detailed, comprehensive and data rich, and the individuals and agencies responsible for creating and maintaining the data series and analytical tools should be commended for their efforts. Most of my comments and recommendations are to build support for the scientific underpinnings of the process. These recommendations seem to fall in 2 general areas: 1) testing the underlying assumptions of the analyses and 2) incorporating uncertainty in the management advice. By component, the primary recommendations are:

1) *River assessment*: conduct a one-time review of the complete spawning stock and freshwater fishery assessment program to ensure that the resulting estimates, which are the basis of much of the management advice, are unbiased and sufficiently precise. Although sufficient detail was provided on ageing, I could not readily evaluate the creel or escapement programs with the information provided.
2) *Cohort reconstruction*: Sensitivity analysis or simulation could be used to determine how the final abundances are affected by uncertainty in input river abundances and catch data.
3) *Forecasting ocean abundance*: I recommend that more statistical work be done with the forecast models to determine the adequacy of the model and to generate estimates of uncertainty in the forecasts.
4) *Forecasts of Catches and Escapements*: Sufficient data is now available to test the underlying assumptions of KOHM, especially with respect to the linear relations between fishing seasons and effort, and effort and catch, and the independence of those relations for areas, months, ages and gear types. Thought should be given to trying to either project the uncertainty in the model inputs through the outputs, or to using the retrospective information to approximate the uncertainty in future forecasts.

Developing estimates of uncertainty is an important analytical task that will bring the Klamath assessment process closer to the "best available science" for fisheries assessment. However, another important task for scientists and analysts is to assist mangers, decision makers and stakeholders in developing ways to work in a risk-based environment where none of the information they are using is certain (e.g. Hilborn et al. 2001). They need to become comfortable with the notion that uncertainty is not a shortcoming of the process, models or the analysts, but is a normal part of the assessment. The communication of the risks associated with management acknowledges that unusual or unexpected events, such as not meeting a target, can happen and that is not the fault of the system or those making decisions. The change in approach from hard targets and goals to thinking about probabilities and risks is significant, but will be increasingly required if the expected increase in environmental variability resulting from climate change causes fish populations to be more unpredictable in abundance, distribution and migration (e.g., Cooke et al. 2004).

Finally, experience along the Pacific coast has shown that pre-season salmon forecasts are always very uncertain, regardless of the nature or quality of the data or models employed. In many intensively managed populations preseason forecasts are used for planning purposes only, and are modified by in-season information on run size, catch rates or other indices of abundance. Given the wide spatial and temporal nature of the Klamath River fisheries, I wonder whether consideration should be given to developing in-season indicators of run size that could be used to update the pre-season forecasts. Further analysis of the catch-effort-abundance database might be useful for the identification of inseason predictors.

List of Material Provided to CIE Reviewers

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STT (Salmon Technical Team). 2006a. Review of 2005 ocean salmon fisheries. Unpublished report. Pacific Fishery Management Council, Portland, OR.
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Consulting Agreement between the University of Miami and Mike Bradford

Statement of Work

Klamath River Fall Chinook Salmon
Assessment Approach and Methods Review

Background

The primary purpose of this technical review is to assess whether the approach and methods presently used to conduct the annual fishery assessment of Klamath River fall Chinook (KRFC) salmon constitute the best available science for this purpose.

KRFC salmon are a key stock for salmon fisheries management in California and Oregon waters. The Pacific Fishery Management Council's (PFMC) Salmon Framework Management Plan identifies explicit annual conservation objectives for KRFC, including (i) at least 35,000 adults must be allowed to escape fisheries to spawn in natural areas (minimum spawner "floor"), and (ii) the number of adults that would spawn in natural areas absent fisheries may be reduced by fisheries by no more than 2/3 (maximum spawner reduction rate). Allocation of the KRFC annual harvestable surplus to various user-groups is also explicit, including the (a) Klamath River tribes share of overall harvest, (b) Klamath River recreational share of nontribal harvest, (c) Klamath Management Zone recreational share of ocean harvest, and (d) California commercial share of ocean commercial harvest. The KRFC ocean age-4 annual harvest rate is also used as a proxy measure of the ocean harvest rate on California Coastal Chinook (ESA-threatened), and for this purpose may not exceed 16%.

Fishery management measures are crafted by the PFMC each year to achieve these annual KRFC objectives. Whether the proposed management measures are expected to achieve these objectives requires an annual assessment of KRFC stock status and the fishery impacts expected under these measures. It is imperative that the approach and methods used to conduct this assessment constitute the best available science for this purpose.

Objectives of the CIE Review

The KRFC annual assessment consists of four principal sub-assessments: (1) estimation of the previous year's river returns, (2) cohort reconstruction of the natural and hatchery stock components based on coded-wire tag recoveries, (3) forecast of the current year's ocean abundance and proportion of natural fish, and (4) forecast of the current year's fishery harvests and spawner escapement under PFMC-proposed management measures. The Center for Independent Experts (CIE) shall review each of these sub-assessments to ensure that the respective approaches and methods constitute the best available science for the respective purposes.

The CIE reviewers must have expertise in the population dynamics and assessment of Pacific salmon, and experience with cohort reconstruction and projection methods is beneficial. Extensive experience in Pacific salmon fisheries dynamics modeling, assessment, management, coded-wire tag analysis, and in-depth knowledge of the Klamath River and its tributaries is desirable.

Each reviewer will be supplied with a document entitled "Klamath River fall Chinook salmon: assessment approach and methods – an overview", and an electronic copy of all reports and papers cited therein. The CIE individual reviewer will review each of the four principal sub-assessments as described in this overview document and the materials cited therein, according to the following terms of reference.

CIE Review Terms of Reference (apply to each sub-assessment):

6. Evaluate the approach: determine if it is adequate and appropriate for the assessment.
7. Evaluate the data: determine if it is adequate and appropriate for the assessment.
8. Evaluate the methods and assumptions: determine if they are adequate and appropriate for the assessment.
9. Evaluate the uncertainty: determine the primary sources of uncertainty in the assessment.
10. Determine whether the data, approach and methods constitute the best available science for the intended purpose.

Specific Activities and Responsibilities

The CIE shall provide three reviewers to participate in a letter review of the KRFC annual fishery assessment approach and methods – two individual reviewers and one reviewer to compile a summary document. A third reviewer, chosen by the SWFSC, will be:

- Dr. Robert Kope (NMFS, Northwest Fisheries Science Center)

The CIE will select three reviewers; two to provide written individual reports, and a third to develop a summary report of the three individual reports. The third reviewer will not develop an individual report, but will be solely responsible for development of the summary report. The CIE individual reviewers' duties shall not exceed a maximum of 7 work days for development of the individual report. The CIE summarizer's duties shall not exceed a maximum of 6 work days for development of the summary document. The reviewers shall conduct his/her review duties from their primary locations, and by conference call as necessary and coordinated through the CIE. The CIE reviewers will write the individual and summary reports on their findings and conclusions regarding the above terms of reference. See Annex 1 and 2 for additional details on the report outlines.

All reports from the CIE individual reviewers and the CIE reviewer responsible for developing the summary document shall be sent to Dr. David Die, via email at david.die@rsmas.miami.edu, and to Mr. Manoj Shivlani, via email at mshivlani@rsmas.miami.edu. The SWFSC shall provide the individual report from Dr. Robert Kope to Dr. David Die, via email at david.die@rsmas.miami.edu, and to Mr. Manoj Shivlani, via email at mshivlani@rsmas.miami.edu by December 7, 2006 for distribution to the CIE summary reviewer. The CIE will not be responsible for review and approval of the report by Dr. Robert Kope. The following table provides the specific timeline for report submission, review and approval.

Activity	Submission	Deadline
Distribution of NMFS documents	Documents provided by the SWFSC to the CIE, CIE reviewers, and the NMFS reviewer.	November 15, 2006
Individual reports submitted	Submission of draft CIE individual reports to the CIE and to summarizer. The report by Dr. Robert Kope will be submitted to the SWFSC, who will provide a copy to the CIE for distribution to the CIE summary reviewer. [/1]	December 7, 2006
CIE approval of CIE individual review reports	CIE reviews and approves the CIE individual review reports. CIE provides final individual review reports to the summary reviewer and to Lisa Desfosse.	December 21, 2006 [/2]
Summary document	Draft summary document submitted to CIE by third CIE reviewer.	January 4, 2007 [/2]
NMFS approval of individual reports	NMFS approves CIE individual reports.	December 29, 2006 [/2]
CIE approval of summary document	CIE reviews and approves summary document and provides to Lisa Desfosse.	January 18, 2007 [/2]
NMFS approval of summary document	NMFS approves summary document.	January 22, 2007 [/2]

[1/] The CIE will not be responsible for review and approval of the individual report by Dr. Robert Kope. The CIE will distribute this report to the CIE summary reviewer upon receipt from the SWFSC.

[2/] Dates assume that all individual reports are submitted to the CIE by December 7, 2006. Any delays in submission of individual reports will result in delays in other activities and potential extension of these deadlines.

Submission and Acceptance of Reports

The CIE shall provide via e-mail the CIE individual and summary reports according to the table of deliverables to Dr. Lisa Desfosse (lisa.desfosse@noaa.gov) for review of compliance with this Statement of Work by NOAA Fisheries and approval by the COTR, Dr. Stephen K. Brown. The COTR shall notify the CIE via e-mail regarding acceptance of the reports. Following the COTR's approval, the CIE shall provide the COTR with pdf versions of the final reports.

Annex 1: Contents of Individual Reviewer Reports

1. The reports shall be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the reports shall consist of a background, description of review activities, summary of findings, conclusions/recommendations, and references.

3. The reports shall also include as separate appendices the bibliography of all materials provided and any papers cited in the Reviewer's Report, along with a copy of the statement of work.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cimas/Report_Standard_Format.html

Annex 2: Contents of Reviewer Summary Report

1. The reports shall be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the reports shall consist of a background, description of review activities, summary of findings, conclusions/recommendations, and references.

3. The report shall also include as separate appendices the bibliography of all materials provided and any papers cited in the Reviewer's Report, along with a copy of the statement of work.

4. The report shall include as appendices the individual reviewer reports used to develop the summary report.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cimas/Report_Standard_Format.html