Klamath River Fall Chinook Salmon Assessment Approach and Methods

Summary Review

By

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January 4, 2007

Executive Summary, findings and recommendations

This report summarises three reviews of the stock assessment and management system for Klamath River Fall Chinook (KRFC) salmon, for which seasons and quotas for harvest management are set by predicting the run with an assessment model and tuning fishing effort and quotas (subject to some allocation constraints) with a harvest model in an attempt to meet specific conservation objectives. The reviews examined a number of reports, memoranda and published papers describing the procedures currently in use. The authors conclude that the data and methods employed in the monitoring and annual assessment of KRFC are among the most detailed, thoroughly documented and analysed for any Pacific salmon stock, and are adequate to support management decisions. There are options to enhance the integration of the assessment and estimation process, but it is not clear that this would lead to substantially different point estimates of the decision quantities (or to different decisions under the present decision rules).

However, there is a need for the testing of assumptions of each procedure in the system and, because fall chinook are often unpredictable in their abundances, 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 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 and in the management advice for KRFC. The key recommendations by task are:

1) *River assessment*. Conduct a one-time review of the complete spawning stock and freshwater fishery assessment programme to ensure that the resulting estimates, which are the basis of much of the management advice, are unbiased and sufficiently precise.

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*. More statistical work is required with the forecast models to determine the adequacy of the model and to generate estimates of uncertainty in the forecasts. Better understanding of annual variability in maturation rates could improve both abundance forecasts and model performance.

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.

5) *Developing and accommodating estimates of uncertainty*. This is an important analytical task that will bring the Klamath assessment process closer to the "best available science" for fisheries assessment. Whilst the change in approach from hard targets and goals to thinking about probabilities and risks is substantial, it will be increasingly required if the expected increase in environmental variability resulting from climate change causes fish population dynamics to be more unpredictable.

6) *Model development*. As the assessment system for KRFC evolves, consideration should be given to developing a "stock synthesis" approach for cohort reconstruction and ocean

abundance forecasting and, possibly, reconfiguring it as an integrated assessment using Bayesian analysis. This has potential advantages over the current cohort reconstruction and forecasting: it employs all data that inform an estimate into generating the estimate; it imposes structure on rate estimates by decomposing fishing mortality rates into year effects and age effects; and it allows characterization of uncertainty in all estimates.

7) *In-season management.* 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, they 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, consideration should be given to developing in-season indicators of run size that could be used to update the pre-season forecasts.

8) *Conservation objectives.* Expand the policy objectives to include considerations of local differences in substocks' productivities, separation of contributions of hatchery strays to the apparent productivity, and the possible degradation of fitness from hatchery introgression. Re-examine the escapement floor in relation to managing for MSY in this light, and state the management objectives in probabilistic terms, distinguishing clearly between target and limit reference points, to make use of the better quantification of uncertainty.

Background and review activities

The Klamath River, located in northern California and southern Oregon, supports a large fall chinook salmon population that is valued by local aboriginal peoples and contributes to important river and ocean sport fisheries and the commercial troll fishery off California and Oregon. The Klamath River Fall Chinook (KRFC) is a complex of naturally reproducing stocks occupying a large basin and augmented by strays from a large hatchery programme. The runs in the last few decades are considerably diminished from earlier historic highs. The Pacific Fishery Management Council's (PFMC) Salmon Framework Management Plan identifies explicit annual conservation objectives for the 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 in the absence of fisheries may be reduced by fisheries by no more than 2/3 (maximum spawner reduction rate). The management of this salmon population is achieved through an intensive information system that predicts river and ocean abundance and impacts of fisheries on abundance, and fishing seasons and quotas are set in an attempt to meet the conservation objectives. The purpose of this review is to consider whether the assessment system for management of the KRFC is the best available science for the purpose.

The assessment system has been examined by three individual reviewers (two provided by CIE, Drs. Bradford and Goodman, and one chosen by the SWFSC, Dr. Kope). Each reviewer was supplied with a document entitled "Klamath River fall Chinook salmon: assessment approach and methods – an overview", and all reports and papers cited therein (available on the RSMAS CIE website), and was requested to review each of the four principal sub-assessments as described in this documentation, according to the following terms of reference.

1. *Evaluate the approach: determine if it is adequate and appropriate for the assessment.*
2. *Evaluate the data: determine if they are 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.*

One reviewer (Goodman) is of the opinion that, since the scientific reasonableness of the approach depends in part on the scientific reasonableness of the conservation objectives stated in the PFMC Salmon Framework Management Plan, the objectives should be evaluated together with the approach and methods. Part of his concern may stem from the fact that the ocean harvest rate on age-4 KRFC is used as a proxy measure for ocean fishery harvest rates on other California coastal Chinook salmon stocks, listed as threatened under the Federal Endangered Species Act, but for which there is insufficient monitoring to assess impacts on the listed stocks themselves. It may, therefore, be pertinent to ask whether the KRFC assessment programme is so intensive that it precludes adequate monitoring and assessment of other salmon stocks in California.

However, this summary review addresses only the CIE terms of reference and is organized to cover the four main components of the KRFC assessment process as listed in the statement of work:

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

Task 2. Cohort reconstruction of the natural and hatchery stock components based on coded-wire tag recoveries,

Task 3. Forecast of the current year's ocean abundance and proportion of natural fish, and

Task 4. Forecast of the current year's fishery harvests and spawner escapement under PFMC-proposed management measures.

The present report summarises the individual reviewers' reports (there was no discussion between reviewers), picking out the main comments against the above tasks and indicating, where necessary, any discrepancies between them. It includes a summary of the main findings and the reviewers' recommendations, that are intended to either improve or support the current assessment system for KRFC salmon. The list of material provided to the individual reviewers is given at Appendix 1, and the Statement of Work agreed between the University of Miami and reviewers of the assessment approach and methods for KRFC salmon is provided at Appendix 2. The individual reviewers' reports are appended to this report.

Task 1: Estimation of the previous year's river returns and of total natural spawners

The individual reviews of the estimation of in-river KRFC abundance are based on the documentation provided in KRTAT (2006a) "Klamath River Fall Chinook Age-Specific Escapement River Harvest and Run Size Estimates, 2005 Run". This is a relatively brief description of an intensive escapement estimation programme, which makes it difficult to provide a detailed review of the assessment process. Note that the summary reviewer has not seen this documentation. Presumably, the methods used in each part of the basin have evolved over time, and have been deemed appropriate in view of physical/logistical considerations, the expected number of spawners in each area, and resource limitations.

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. Accurate 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.

In response to the CIE Terms of Reference:

1. *Evaluate the approach*: This is the most intensively monitored Chinook salmon stock in the world. The methods used are well documented, and the approach to estimating the abundance and age structure of the run is adequate and appropriate. The monitoring of tribal harvest using stratified effort and CPUE sampling is a statistically sound approach, but the accuracy of harvest estimates based on roving creel census is uncertain.

2. *Evaluate the data*: The reviewers were only provided detailed information (i.e., raw data) for the ageing component of the assessment. The volume and detail of the data collected

in the Klamath basin are generally unattainable in other river systems because of workforce and funding limitations. Over 20% of the total run in 2005 was sampled for ageing structures and this certainly appears adequate. Escapement and terminal harvest data are collected by two federal agencies, one state agency and two tribal agencies. Whilst virtually all potential spawning locations and all significant catches are monitored, little information is provided to evaluate the accuracy and precision of the creel census and catch reporting for the recreational and tribal fisheries, and it is difficult to comment on the adequacy of these programmes. Similarly, details about the raw abundance data used to arrive at the subcomponents of the abundance estimate have not been provided and are difficult to evaluate.

3. *Evaluate the methods and assumptions*. The coverage of the basin is exhaustive and the methods used to estimate the abundance of salmon in the river are standard practice and provide data comparable to those available elsewhere. However, there is no information to evaluate many of the assumptions in the available documentation, and it is suggested that a review of the methods be conducted to assess any sources of bias and, if appropriate, identify means to develop corrections.

   The main points are:

   a. Hatchery escapements are enumerated and many of the naturally spawning substocks are estimated using mark-recapture techniques and video counts. These are the most accurate methods available for estimating salmon escapement, though bias in mark-recapture programmes (tag shedding, differential mortality or vulnerability to recapture of tagged fish, non-random tagging or recovery) may lead to overestimates of abundance.

   b. Sex-specific differences in carcass recovery can lead to biased estimates: male spawners tend to wander after spawning; jacks may not have affinity for any specific redd or spawning area; and it is likely that fewer male carcasses are recovered than females. The situation is further complicated if there are sex-specific age structure differences in the spawning population. Non-random recovery and sampling of carcasses and/or tags 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.

   c. There is no information on the origins of the hook and net mortality rates, but they would seem to be low for a situation where, in recent years, disease problems have been a significant source of mortality. In these circumstances, the stress associated with capture and release may be important.

   d. It is not apparent whether redd counts, used for a few of the smaller spawning aggregates, are accurate, nor if the use of a 1:1 sex ratio for scaling the redd counts is appropriate. These can be evaluated with data from other calibration studies, if Klamath-specific data are not available.

   e. Considerable effort has been applied to ensure that 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 do not have a large impact on adjacent small ones.

4. *Evaluate the uncertainty:* Uncertainty in this stage of the process could have considerable influence on the results of the fishery model. Each of the methods used has a number of assumptions which, if violated, can result in biased estimates. In particular, 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. 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.

   Some questions regarding primary sources of uncertainty are:

   a. Is the sampling rate of age-2 and older fish in the river recovery programmes proportional to their abundance?

   b. Is it realistic for the sports fishery to capture nearly half the jacks in the system, yet land (with bag limits) only 2.5% of the adult population, and can the creel census estimate of age-2 catch be reconciled with the in-river and total age-2 abundance? One interpretation is that the number of age-2 spawners in the system has been overestimated, or the creel census is biased in some fashion. There is evidence that the abundance of age-2 fish in Klamath carcass data would have been substantially overestimated because of ageing errors, unless a correction had been performed.

   c. Are the capture-recapture estimates unbiased in relation to sex and age?

   d. Accuracy of the order of 83-95% in reading scales of known-age fish will substantially affect both the precision and bias of estimates of age composition, particularly when age classes differ in their contributions by more than an order of magnitude. The approach used by the KRTAT to correct scale-based age compositions for the bias that results from ageing errors appears to be valid, but there is a trade off between removal of the bias in age compositions (assuming the validation matrix is known) and increasing the variance of the estimates of escapement by age.

   e. The proportion of escapement that is of natural origin is estimated by subtracting the estimated returns of hatchery-origin fish from estimated total return, based on CWT recoveries and sample rates. Approximately 50% of the escapement in 2005 was to natural areas, but some portion of this was due to hatchery strays. The monitoring of spawning escapement could be substantially improved by mass marking hatchery production to allow unambiguous identification of returns of natural and hatchery-origin fish.

   f. 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. The recovery data could be stratified to estimate changes in the rate of recovery of tags over time (in the river), as well as spatially to determine if the tags are well distributed in the river.

g. It is difficult to determine 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 from the available information. This could be checked by making sex-specific population estimates, but no reference is made to such analyses in any step of the Klamath assessment process.

5. *Determine whether this constitutes the best available science for the intended purposes.* The KRFC sampling programme is comprehensive and consistent with practice in many other jurisdictions, and the escapement is probably monitored more intensively, and analysed and documented more thoroughly, than any other stock of Pacific salmon. This probably meets the criterion of “best available science”. However, the documentation provided does not indicate whether potential biases that are well-known in spawning ground assessments have been evaluated, 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.

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 the review.

1. *Evaluate the approach:* Cohort reconstruction is required to generate an historical database of abundances and exploitation patterns for the forward-forecasting harvest model. The approach used for KRFC (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, and is not conducive to generating estimates of uncertainty for model predictions, nor for testing the appropriateness of the approach. In one sense, the data available for a programme of this size are a constraint rather than a design option, since the analysis depends heavily on the existing time series of data.

   Nevertheless, the analysis is simple and straightforward, effectively uses all of the pertinent past information, and includes enhancements to methods used elsewhere. The length-at-age analysis used to estimate the proportion legal is more detailed than that available for other stocks, both on temporal and spatial scales. The use of gear-specific release mortality rates for the recreational fishery is another refinement that is implemented on a finer scale than elsewhere, in that it is weighted by the annual prevalence of mooching in the recreational fishery. The main alternative approach, statistical catch-at-age modeling, estimates parameters from model data and can account for uncertainty and model fit (Savereide and Quinn 2004). Since this would require modeling of the fishing effort and catchability in each of the 7 different management units for KRFC, any benefit may not be worth the effort.

2. *Evaluate the data:* The primary inputs for the cohort reconstructions are the age-specific river abundances (see *Task 1*), and the data on CWT recoveries from the fisheries, which are probably the best available for any Pacific salmon stock. A great deal of effort was put into correcting errors in the CWT database: for example, if they included data values from landings into ports or at times that were closed, or indicated a length that was less than the minimum legal size. This process does not catch all errors, however, and by correcting or discarding only a select portion of the data records, it may bias what remains. Thus, the effect of omitting erroneous data should be evaluated.

   The overall rate of CWT marking from the two hatcheries is of a typical level, and the sampling rate of the catch (~20%) is appropriate, though no details are provided on the representativeness of the sampling programme, which it is assumed has remained relatively consistent over the time series. The breakdown of the CWT data by year, age, release type and area/gear can result in relatively few CWTs per stratum, especially in years when abundance is low. The total number of CWTs recovered relative to the total catch by year suggests a ratio of about 1:100 to 1:200, and the ratio of recovered CWTs to estimated pre-season abundances is usually much lower than that, indicating 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.

   Data on the naturally produced component of the age-specific terminal run (the natural component) are among the best available for any Chinook salmon stock, with the caveat that they have a higher coefficient of variation than the component represented by escapement to natural spawning areas.

3. *Evaluate the methods and assumptions:* Along with the estimates of absolute harvest and spawning escapement, the cohort reconstruction model used for KRFC provides parameter estimates and state estimates for the natural and hatchery-origin components. It is typical of other cohort models used for obtaining abundance indices of chinook salmon on the Pacific coast, and appear to be adequate and appropriate for the assessment. Each cohort is reconstructed based on the estimated numbers of natural and hatchery stock components in the escapement, based on CWT recoveries, and a backwards (in time) reconstruction of earlier abundances raised 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. The scaling to absolute abundance of estimates of the previous year's river returns of natural spawners is based on combinations of redd counts, weir counts, and carcass mark-recapture estimates. It is suggested that a comparison of these abundance indices might help to verify the accuracy of the abundance estimates.

   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 a year-specific analysis (e.g. Goldwasser et al., 2001). Ocean mortality is usually assumed constant, but could vary with coastal productivity or other factors. Only in a 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).

The model also assumes that natural mortality is distributed evenly across months, based on assumed annual rates that are similar to those used for other chinook populations, although there is little justification for those values in Mohr (2006b) or KRTT (1986). If (as seems likely) mortality is higher during the winter months, lower summer mortality rates will tend to reduce reconstructed abundances during the fishing season, but make little difference to year on year changes.

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 in the model's outputs, and it is difficult to determine the primary sources of uncertainty as there are many inputs that contribute to estimates of the age-specific ocean abundances. There are no estimates of the uncertainty in age-specific river abundances, which is likely to be 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.

   The assumption that hatchery CWT release groups are fully representative of the natural component of the stock is a major source of uncertainty. Differences in growth, marine distribution or migration timing, could all contribute to discrepancies between the vital rates experienced by hatchery and natural components of the stock. Though anecdotal evidence suggests that this is a reasonable assumption, as long as the surrogate hatchery stock is closely related to the natural stock it purports to represent, this source of uncertainty could be evaluated by implementing a natural stock tagging programme in the Klamath basin, or possibly, through implementation of a systematic genetic stock identification (GSI) programme to analyse stock composition of ocean fisheries.

   Another source of uncertainty, at least for the most recent year's assessment, is the reliance on an estimate of ocean abundance that is currently generated from the terminal run by assuming an average maturation rate - the same as in the stock forecast.

   Most other assumptions underlying this analysis are unlikely to contribute substantially to uncertainty. For example, natural mortality rates are poorly known, but as long as the same rates are used in cohort reconstruction as are used in the forward projections of the KOHM to assess proposed regulations, errors will tend to cancel out.

   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 potentially reduce bias and improve 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, and the data and methods used for the cohort reconstruction are among the best currently applied to management of Pacific salmon stocks. However, an assessment that uses point estimates as a basis for later estimates is not at the forefront of modern analytical methodologies.

One approach that appears not to have been investigated is the application of a "stock synthesis" based on separable VPA (e.g. Fournier and Archibald 1982). Rather than analysing each cohort independently to calculate point estimates of abundance and vital rates, separable VPA parses vital rates into age effects and year effects to reduce the number of parameters estimated, and can use all data simultaneously to find the set of initial abundances, age effects and year effects that provide the best model fit. Implementation within a framework such as AD Model Builder can also provide estimates of the variance of all quantities estimated, conditioned on a number of assumptions. However, implementation would be a major undertaking, since it requires many more assumptions than the simple cohort reconstruction, and there is no guarantee that it would provide more useful information.

The most advanced approach to this type of analysis, statistical or Bayesian catch-age modeling, can better account for uncertainties and enforce reasonable constraints on estimates, but is 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 significantly improve the scientific underpinnings to this part of the assessment process.

In many jurisdictions, GSI is being used to allocate catch to populations. This 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 large and an adequate baseline of "stock" standards is required for its use. Information on the catches and distributions of other populations in the fishery areas also becomes 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 are the standard tools used for forecasting salmon abundances along the Pacific coast when age-structured terminal run data and reconstructed ocean abundance data are available. This approach requires the development of a predictive relation based on past data. For KRFC, 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).

   The scatter about the regression line in Figure 1 of KRTAT (2006b) suggests that there has not been particularly good agreement between the forecasts and subsequent reconstructed ocean abundance. The proportion that is of natural origin is also estimated by age using a sibling regression, which is probably an improvement over the previous methodology that simply used a recent average of this proportion. Nevertheless, the reviewers consider that this approach is adequate and appropriate.

2. *Evaluate the data:* The data used in the forecast models, age-structured estimates of terminal run and ocean abundance, are among the best data available for any Pacific salmon stocks (see 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 depress the slope of the regression, the extent of the bias depending on the ratio of the variance 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, this 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 and assumptions:* The forecast of the current year's ocean abundance and proportion of natural-origin fish is a straightforward regression based on the cohort analysis. The results are used with estimated rates to forecast the current year's harvests and spawner escapement under proposed management measures. The use of a simple ratio estimator may not be appropriate, given that the variance of the error in the values is not constant, and can change from one observation to another. For this reason, 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.

   A plot of the data for the age 2-3 regression in Figure 1 of KRTAT (2006b) in log space (see Bradford review) indicates that the prediction of the age 3 abundance from the model for 2006 is about 77 000 fish, and this 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, 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 KRTAT (2006b) highlight two points: (1) forecasts are always uncertain and a wide range of values are likely 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.

   The abundance forecast assumes that maturation rates at age are constant, or at least stationary. Maturation rates are known to differ between the two hatchery stocks and between different release strategies. They also probably differ between the natural sub-stock components originating from the Klamath and Trinity basins and possibly between the different major sub-basins within the Klamath. Whether the maturity schedule is actually stationary can be evaluated by plotting time series of the regression residuals and conducting autocorrelation analyses for serial independence. There do appear to be time trends in the age at maturity data, and it might be worth searching for correlations across ages (i.e. residuals from the 3 siblings), aligned by brood year and calendar year, to see if the uncertainty in age-specific estimates covaries among age groups or years.

   Differences in the relative abundance of the various stock components, coupled with differences in maturation rates between them, will produce differences in estimates of the proportion of a cohort spawning in natural areas, even if the age-specific straying rates of hatchery fish do not vary. However, the KRTAT has investigated disaggregation of the hatchery components and the natural stock for the purpose of forecasting abundance, and this did not improve the accuracy of the aggregate stock forecast. It is unlikely that further disaggregation of the forecast of the proportion spawning in natural areas would be fruitful.

4. *Evaluate the uncertainty:* Uncertainty in the abundance forecasts is going to be significant given the scatter in the regression plots (Fig 1 of KRTAT 2006b). The primary source of uncertainty appears to be variability in age-specific maturation rates (see above). Unfortunately, this variability appears to be greatest in younger ages (age-2 and age-3), where maturation rates are low but which have the greatest influence on forecasts of ages 3 and 4, the ages that make up the bulk of ocean harvest and of the coming year's terminal run and subsequent spawning escapement.

   It appears that this variability is autocorrelated and may be influenced by environmental factors. Mohr's proposal, to investigate this variability and possible relationships to environmental causes, will only be useful in forecasting abundance if relationships can be found either with factors that have sufficient lead time in their effect, or can be forecast themselves.

   A recent forecast document for Fraser River sockeye salmon: http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2006/RES2006_060_e.pdf , provides examples of dealing with diverse sources of information and competing forecast models.

5. *Is this the best available science?* The methods and data used for forecasting KRFC abundance are the best currently available, though 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 to find the best format for presenting uncertainty information, and to assist managers to find ways to use this in decision making. An example is provided in Prager and Mohr (2001).

   Age-specific forecasts of ocean abundance currently rely on a single piece of information, terminal run size of the same cohort the prior fall. Marginal improvements might be obtained by using a stock synthesis approach, which would incorporate all data that inform ocean abundance in a likelihood framework to develop abundance estimates. This includes ocean harvests and terminal runs from the same cohort at all prior ages, and even from adjacent cohorts. Unfortunately, the ocean harvest data only contain information about CWT fish and would do little to improve estimates of the natural component. Implementation of a coastwide systematic GSI programme to estimate stock composition of ocean fishery landings would provide an estimate of total contribution of Klamath Chinook, but GSI cannot currently distinguish between spring and fall runs of Chinook salmon from the Klamath basin, and thus could not inform harvest management at the current stock resolution required by fishery management.

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), Mohr (2006 c,d,e) and Prager and Mohr (2001).

1. *Evaluate the approach:* The KOHM uses historical catch and effort data combined with reconstructed abundances to forecast the impact of a proposed fishery management regime on current stock abundance. This approach is similar to other harvest models used for projecting the impacts of fishery regulations on Chinook and coho salmon stocks, though it partitions time on a monthly scale, which is on the fine end of the range of models currently in use (MEW 2004; CTC, 2005). All harvest models use a single pool model in which impacts occurring in one time step are deducted from the ocean abundance in the following time step, and the same ocean abundance is available to all ocean fisheries in the next time step. Given the richness of the catch and effort database, the use of an empirical approach in the KOHM forecast model is adequate and appropriate. There are no state-dependent functions (e.g. effort in relation to previous catches or forecasts, etc.) that might 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 fishing 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. 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 so-called “unusual” events will be more likely to occur as more years of data accumulate, and may also be more likely if there is increased environmental variability (e.g. that associated with climate change).

   The KOHM also includes sub-models that partition the forecast of ocean impacts, effort and encounter rates. In the past three years (2003-2005), the age-4 ocean impact rate has been substantially higher than forecast by the model. The fine-scale resolution of the impacts in the KOHM has allowed assessment of where and how the impacts exceeded forecast values, i.e. KRFC were more available to fisheries in 2003-2005 than they had been on average in prior years, particularly in port areas south of the Klamath Management Zone. However the model sheds no light on why this occurred.

2. *Evaluate the data.* The main sources of data for the KOHM are primarily outputs from the cohort reconstruction reviewed in Task 3, forecasts of current year’s abundance, and the regulation and effort database. The data that feed into these analyses are among the best available for Pacific salmon stocks, but the performance of abundance forecasts and the recent forecasts of fishery impacts are below the level of precision demanded by the current management objectives and constraints.

   The estimates of commercial effort are derived from the total landed catch and the ratio of the mean catch and effort for the sampled boats, and are thus based on an assumed linear relation between effort and catch (passing through the origin) with a symmetrically distributed error structure. No analyses of these data are indicated, but it would appear that more detailed work is possible, given the extent of the database. 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 equation (2) avoids the issue of non-random sampling of boats and thus trip lengths, it assumes that large and small boats have the same average catch rate (catch/day). This needs to be tested.

Because the estimates of effort are based on landings, 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 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 procedure for estimating sport fishery effort are not provided and the adequacy of these data cannot be evaluated.

3. *Evaluate the methods and assumptions.* Fishery harvest models used to forecast impacts in salmon fisheries start with forecast abundance, subtract projected harvests and incidental impacts, and divide the remaining abundance between projected spawners and immature fish that will remain in the ocean. Whilst these methods are adequate and appropriate, the outputs from the models are only as good as the forecasts that feed into them.

   Other models used to forecast the impacts of Pacific Ocean salmon fisheries rely on fixed base period values, against which they scale current year's stock abundances and fishery impacts (CTC 2005, MEW 2004). Over the years, the base period may lose relevance for current patterns of stock and fishing effort distribution. It is rare that data are developed for a new, more recent base period. By parsing ocean impact rates into effort and contact rates per unit of effort, the KOHM sub-models used to predict effort and contact rates allow the incorporation of new data on an annual basis. This represents a substantial improvement over other Pacific salmon harvest models.

   At the core of the model are two 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 (which is similar to catchability) is based on the total ocean abundance, as there are no area-based predictions of abundance. The sub-models used to predict contact rates, effort per day open, and the current year's abundance, all rely on the adequacy of average rates across the range of efforts and fish abundance, either an historic average or a recent average, to characterize the current year's rates, although a formal justification for this approach has not been provided. 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.

   A visual examination of the data in Mohr (2006e) suggest that there are non-linear relations between effort and days open, which 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 estimates of fishing mortality. 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. Despite the improved updating feature of the KOHM, investigation into annual deviations from the average are encouraged.

Finally, there is 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.

4. *Evaluate the uncertainty.* The forecasts produced by the KOHM are the adult spawning escapement destined for natural areas, the spawner reduction rate, the age-4 ocean harvest rate, and the allocation of harvest among different user groups. Whilst there is no explicit provision for uncertainty analysis in KOHM, there is substantial uncertainty in each of the inputs to the analysis- the prediction of ocean abundance from sibling models, variability in maturation rates, the prediction of contact rates and, to a lesser extent, uncertainty in the relationship between management measures and effort in the fisheries. These all affect the accuracy of forecasts of ocean fishery impacts, and the propagation of uncertainty through the model thus affects all forecasts required to inform harvest management.

   There is considerable variability in the effort and contact rate predictions that, 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. For example, correlations of residuals across gear types within areas might be an indicator of inter-annual variation in local abundance. Correlations across all areas and gears might be indicative in errors in the estimation of abundance, whilst 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 used 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.

   Variability in maturation rates affects both the accuracy of the current year's abundance forecasts that feed into the KOHM, and the proportion of ocean abundance in the current year that will mature and thus become available to river fisheries and spawning escapement. This affects all of the forecasts required by management except the age-4 ocean harvest rate.

   The ultimate measure of the uncertainty is the difference between the key model predictions and the actual outcomes. A plot of all the data for predicted and observed ocean catches from KRTAT (2006b, Table 3) with the axes in logarithmic form (see Bradford review) shows that, although the general magnitude of the harvests are predicted quite well, there is still substantial uncertainty. This uncertainty is proportional to the prediction (uniform residuals on the log scale), appears to be in the order of at least +/- 100%, and the errors are similar at high or low abundances. 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.

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), it is possible to identify the major contributors to forecasting error.

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 to be 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?* The KOHM employs a similar fundamental structure to other harvest models used to evaluate the impacts of proposed salmon fishery regulations, but it has some enhancements. The reviewers consider that the approach and methods are making effective use of the available data to forecast harvest and abundance. However, 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) needs to be addressed before the model can be considered "the best available science".

   The critical measure of uncertainty, in the context of how well the assessments are used for management, is the comparison of pre-season and post-season assessments of spawning escapement. The four comparisons provided reveal a substantial error (ranging from 150% in the direction of underestimates to 30% in the direction of overestimates). This is not surprising, considering the likely estimation error in both the quantities being compared.

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

   The provided management strategy evaluation shows that the optimum (in terms of long-term average harvest) location of the escapement floor is reasonably robust to the plausible range of error variance, though the error does degrade the mean performance, as expected. The management strategy evaluation also indicates that no parties are being systematically cheated in the allocation as a result of the uncertainty.

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 enables managers to evaluate the potential for their regulatory changes to produce the desired or predicted outcomes.

Summary and Recommendations

The Reviewers agree that 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. There are options available to enhance the integration of the assessment and estimation process, but it is not clear that these would lead to substantially different point estimates of the quantities used in the present decision system. As with most of the comments provided above, the following recommendations of the reviewers are intended to help support the science underpinning the process:

1. *River assessment*: conduct a one-time review of the complete spawning stock and freshwater fishery assessment programme to ensure that the resulting estimates, which are the basis of much of the management advice, are unbiased and sufficiently precise.

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*: More statistical work is required 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.

5. *Future data collection:* Cost must be taken into account with respect to changes in the design for future data collection. Bradford recommends that a specific power analysis would quantify how much the precision of the assessment would be improved by an increase in quantity and quality of data, achieved by a specific sampling design, so that the benefits of improvement in the estimates could be weighed against the cost of the added data. However, Goodman could see no obvious opportunities where a particular directed change, of modest magnitude and cost, in data collection would make a disproportionately large improvement in precision, given that the assessment targets the current stated policy objectives. He suggests that it might be worth carrying out additional calibrations to pin down the correct expansions for the spawning ground estimates, which would improve the certainty of the post-season estimates of spawning escapement, though it may not improve the pre-season estimation that drives the actual decisions.

6. *The relationship between maturation rate and environmental factors*. Maturation rates play a central role in abundance forecasts, and in determining the proportion of current ocean abundance that will mature and leave the ocean to become available to river fisheries and spawning escapement. Better understanding of annual variability in maturation rates could improve both abundance forecasts and model performance.

7. *Changes in availability or vulnerability of KRFC*. Evaluation of the model performance clearly identified anomalously high Klamath River fall Chinook contact rates as a major contributor to ocean impact rates in 2003-2005 and that were substantially higher than forecast. In an attempt to correct this apparent bias in forecasting contact rates for 2006, only the most recent 3 years data were used. It would be more satisfactory to understand why Klamath fall Chinook were more vulnerable to ocean fisheries in these years, than to rely on ad hoc adjustments to the model.

8. *Developing and accommodating estimates of uncertainty*. This is an important analytical task that will bring the Klamath assessment process closer to the "best available science" for fisheries assessment. However, scientists and analysts must assist mangers, decision makers and stakeholders to develop 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 this 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 substantial, 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).

9. *Model development*. The development of a "stock synthesis" approach for cohort reconstruction and ocean abundance forecasting could be a large task, but it has potential advantages over the current cohort reconstruction and forecasting: it employs all data that inform an estimate into generating the estimate; it readily allows incorporation of new data such as GSI; it imposes structure on rate estimates by decomposing fishing mortality rates into year effects and age effects; and it allows characterization of uncertainty in all estimates. As the assessment system for KRFC evolves, consideration should be given to reconfiguring it as an integrated assessment and using Bayesian analysis. This can use all the present underlying models, but would lead to a system that is easier to review and for which uncertainty quantification and power analysis are easier.

10. *In-season management*. 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, 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 in-season predictors.

11. *Re-examination of conservation objectives*.

a. The key management objective for KRFC is the escapement floor, which is a robust and well-used management strategy for salmon fisheries and has a biological foundation in relation to managing for MSY. The assessment of the escapement floor for the KRFC assumes a dynamically homogeneous closed population. However, the natural spawning population is certainly not closed and probably not dynamically homogeneous. Hatchery-spawned fish stray to the natural spawning grounds in non-trivial numbers in this system. The per capita productivity in natural spawning of hatchery spawned and natural spawned fish have not been estimated separately in the KRFC, and it is generally suspected in the science that these will differ. The estimation of MSY escapement for KRFC could, therefore, profitably be re-examined in this light.

b. The Klamath basin presents opportunity for development of local salmon stocks with different productivities and adaptations. These appear not to have been estimated for the KRFC, so the extent of these dynamic differences is not known. If there are substantial differences of productivity among stocks, managing harvest for MSY of the aggregate will overharvest the less productive stocks, and could eliminate some of them, with consequent loss of local adaptations, if present, and loss of genetic resources from the population as a whole. In this respect, the aggregate MSY objective is probably under-protective, if preservation of local subpopulations, local adaptation, and genetic diversity are goals of management (though the background material provided does not indicate policy attention to fitness considerations in the PFMC Salmon Framework Management Plan).

c. There should also be concern about the degradation of fitness of the natural spawning population due to introgression with hatchery stock straying into the natural spawning area. If fitness of the natural stock is a goal, it would be sound practice to limit hatchery production to meet a constraint on maximum fraction of hatchery strays in the natural spawning population. In such a large, important, fishery as the KRFCs, it would make scientific sense to update the Management Plan conservation objectives in this respect and to monitor specifically for fitness effects.

d. It is unclear whether the escapement floor is a limit reference point or a target reference point. The operation, as described, of setting each year's quotas and effort restrictions treats the escapement floor as a target reference point (for MSY, and accordingly will be missed with appreciable frequency). However, the fact that missing this target in three consecutive years triggers a determination of overfished, and consequent requirement for a rebuilding plan, treats the 3-year status as a limit reference point. It might be prudent to set the target higher (and manage against it) in order to reduce the frequency of violating the limit, both in overall stock conservation terms and to protect less productive sub-stocks. Note that the spawning escapement floor has recently not been attained, and may not be attained in the immediate future. It appears that there has been insufficient policy attention to the implications of uncertainty in this respect, though the technical documents show an awareness of the issues. A restatement of the management objectives in probabilistic terms, distinguishing clearly between target and limit reference points, would create an opportunity to make use of the better quantification of uncertainty.

Finally, it should be noted that this kind of review within the CIE framework stops short of attempting to duplicate any of the calculations or to compare the results to alternative analyses. Whilst this would be a very large undertaking for an assessment procedure of this complexity, the opportunities for investigating calculation or coding errors, and the possibilities latent in the exploration of alternative analyses, are probably worthwhile.

Appendix 1. List of Material Provided to CIE Reviewers

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Appendix 2. Consulting Agreement between the University of Miami and Reviewers

<u>Statement of Work</u>

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):

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.

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.

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