**Clearwater BioStudies, Inc.**

23252 S. Central Point Road Canby, Oregon 97013 (503) 266-8724

# TECHNICAL MEMORANDUM

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| To: | Ian I. Courter, Cramer Fish Sciences |
| From: | C.W. Huntington, Aquatic Biologist |
| Subject: | Comments on multiple technical memoranda related to modeling Klamath R. coho |
| Date: | 07 June 2007 |

As indicated in previous communications, I am working for and with the Klamath Tribe to review, and possibly contribute improvements to, the model of Klamath River coho that you are developing for the Bureau of Reclamation. The following are my primary comments after reviewing the eight model-related technical memoranda that Cramer Fish Sciences (CFS) has distributed to interested parties since last fall. Because I am entering your review process a bit late, I have kept the comments focused on several key model issues and have tried to account for the model adjustments CFS has suggested in its “response briefs” to other reviewer comments. Each comment is identified by the model issue it addresses and by the specific technical memorandum in which that issue is identified and discussed by CFS.

The eight memoranda make clear that your consulting group has put much effort into acquiring the information available on Klamath River coho and quite a bit of thought into how one might assemble this information into a functional model for these fish. Developing a model that will reasonably represent the performance of coho in the Klamath system, where the fish are often pushed to and beyond their physiological and/or behavioral limits, will be no easy task. One of the biggest challenges you seem likely to face is in conveying the degree to which any model you produce will be a work-in-progress whose early, unvalidated outputs will have high levels of uncertainty.

My hope at this point is to obtain a working copy of your preliminary model as soon as it is available so as to develop a better understanding of its structure, its sensitivities, and whether the model's behavior is as one might expect. Getting a better handle on these aspects of the model will help me better understand the relative significance of some of the issues I raise and, potentially, to suggest ways that its performance might be improved.

## SPECIFIC COMMENTS

### Model Calculations of Coho Emigration Survival (Technical Memo 4)

For coho emigration and other components of the model that is under development, it would be helpful to have a clearer sense of how the model will be structured so as to account for the duration of fish exposure to stressors. Without a better understanding of this aspect of the model it is a bit difficult to comment fully on the appropriateness of your stressor/survival curves ("scalars") for temperature or other potential stressors.

### Temperature Effects on Coho Smolt Emigration Survival (Technical Memo 4).

How will the temperature "scalar" be used to account for the duration of fish exposure to thermally stressful conditions within each mainstem reach between a coho's natal stream and the estuary? Without this information, it is difficult to fully evaluate or comment upon Figure 9. If the assumption is that each fish will be exposed for 14-days to mean daily temperatures equivalent to those plotted in the figure, the survival rates given for warmer temperatures, particularly above 22-23$^{o}$C, seem high unless the fish have behavioral options for reducing thermal stress (i.e., refugia).

### Flow Effects on Coho Smolt Emigration Survival (Technical Memo 4).

It is difficult to agree with an analytical approach that uses a set percentage (~80%) of recent (significantly altered) median out-migration flows to define those that ought to be satisfactory for coho in the mainstem Klamath. The basic reasoning behind the flow "scalar" proposed in the technical memo is apparently that a set percentage of recent median flows during the out-migration period may be functional for smolts in the Klamath because they seem to be relatively functional for smolts in other significantly altered systems in the region.

For me, the reasoning just outlined raises three questions that should be answered. First, are there reasons to think that the other systems on which the assumed percentage of is based are similar to the Klamath? Second, are there reasons to believe that out-migration conditions along the lower Yakima or Snake rivers are similar to those on the Klamath? Finally, do we believe that these other rivers were historically similar to the Klamath and/or have flows that have been compromised to same degree and in similar ways to those in the Klamath?

My sense is that available data on the quantitative relationship between flows and the migratory success of smolts that pass downstream through the lower Yakima or lower Snake rivers is at best weakly related to the functionality of smolt migration conditions in the mainstem Klamath. The smolt migration data from the lower Yakima River are affected by fish passage around irrigation diversion dams and through a Columbia River reservoir (Lake Wallula) whose environmental conditions may be only marginally related to altered Yakima flows. The lower Snake is a series of four dams and reservoirs that pose migration difficulties that can be severe enough during years of low flow that there have been discussions of dam removal. Neither the lower Yakima nor the lower Snake really serves as a template for good migration conditions.

In the near term it would seem appropriate to begin relating migration success to some index of natural runoff, not simply to assume that recent modified flows reflect some sort of norm. Given existing data limitations, the simplest way to develop such a “scalar” for coho migration survival down the Klamath might be to establish multiple explicit, ecologically based hypotheses about how fish migration behavior or rate (and thus the duration of exposure to prevailing stressors) might relate to river discharge within specific segments of the river. These hypotheses could be informed by a careful examination of available smolt telemetry and other data (including hydrologic and water travel time information), expressed as differing migration rate curves, and used to test the sensitivity of model outputs to varied migration-flow relationships. After additional years of smolt telemetry work have been completed by the USGS, a better understanding of the migration patterns of coho in the river should improve the ability to estimate the effect flow has on fish migration rate (and thus on the duration of fish exposure to potential stressors that in many cases are themselves also related to flow).

## Rearing Capacity of the Mainstem Klamath Below Iron Gate Dam (Technical Memo 5)

My understanding of your model is that you intend to assess the mainstem Klamath's potential to support coho parr between Iron Gate and the Shasta River by using weekly flows, flow-habitat area relationships, and a temperature "scalar" to calculate the summer minimum of weekly carrying capacities. The underlying assumption in this "bottleneck" approach seems to be that the capacity to rear coho parr in this reach of the river is determined by conditions during the worst week and, by extension, that conditions outside this week may not be nearly as important. It is not clear to me that this approach is entirely on the mark, because it suggests that a river's capacity to produce coho parr might be similar if water temperatures averaged 21-22$^{o}$C during each of 10 consecutive weeks as it would if the temperatures averaged 21-22$^{o}$C over a period of only one week. As indicated earlier in my comments, your model will probably need to account for both the magnitude and duration of fish exposure to stressors.

## Temperature Effect on Rearing Capacity (Technical Memo 5)

The assumption that high temperatures (without consideration of disease effects) will not cause increased mortality of rearing coho unless temperatures are at or very near incipient lethal levels seems contrary to existing models of salmonid performance. It may simplify the difficult task of modeling coho salmon in the mainstem Klamath, but could also raise skepticism about your model results. If coho performance within your model emphasizes diminished rearing space as the factor controlling coho performance during summer to the exclusion of the potential for accumulated temperature-induced mortality, it seems likely to over-estimate fish productivity. If so, this would allow the fish to persist at low levels of abundance despite substantially hostile conditions (i.e., in cases where they might not actually do so) provided the area of habitat to which you apply your temperature "scalar" is large enough that even a small fraction of the habitat is still a significant quantity of habitat.

Equation 3 on page 14 seems to be in error, and produces a logistic curve that yields 95 percent values for your temperature "scalar" at WAT = 17$^{o}$C, not 16$^{o}$C as stated in the text.

*Analysis of Patterns of Coho Abundance Versus Temperatures, on Pages 17-19*. Recognizing that the high levels of food availability in the mainstem Klamath may improve fish performance at high temperatures, I am not sure that this section provides an entirely convincing argument that the temperature "scalar" you suggest for decrementing coho carrying capacity is consistent with available data. My primary concern here is that your linkage between temperature logger data from sites on Oregon Coast streams and coho abundance data from sites on the same streams but as far as 2 km from the logger sites seems likely to introduce errors that will tend to over-estimate coho tolerance of high temperatures (i.e., fish will be suggested as having been present or abundant at some high temperature logger sites when in fact they may have been absent or very sparse). For example, a re-analysis of monitoring data I collected at 10 locations on 3 western Oregon streams sometimes used by coho showed that maximum weekly average temperatures (MWATs) differed by as much as about 3$^o$C within a distance of 2 km along a given stream in the same year (Figure 1). Further, data I have been able to acquire on coho abundance at 53 different locations on western Oregon streams where fish sampling did occur where water temperatures were logged appear to show coho parr abundance declining more quickly at higher temperatures than is suggested by your analysis and the proposed temperature "scalar" (Figure 2). Given that the temperature "scalar" looks likely to be important to your model's accuracy in predicting coho performance in the mainstem Klamath immediately downstream of Iron Gate Dam, and in tributaries, this is probably an issue that will warrant further examination.

## Estimating Capacity in Tributaries to the Mainstem (Technical Memo 5)

Your estimates of coho smolt capacity in the Klamath's tributaries seem high given the current status of the basin's runs. Is it possible that winter floods have a greater effect on fish performance in these areas than you are accounting for at present? This factor, combined with what seems to me to be an overly generous temperature "scalar" for coho rearing capacity, at least for streams that do not have unusually high food abundance, might help explain the apparent discrepancy.

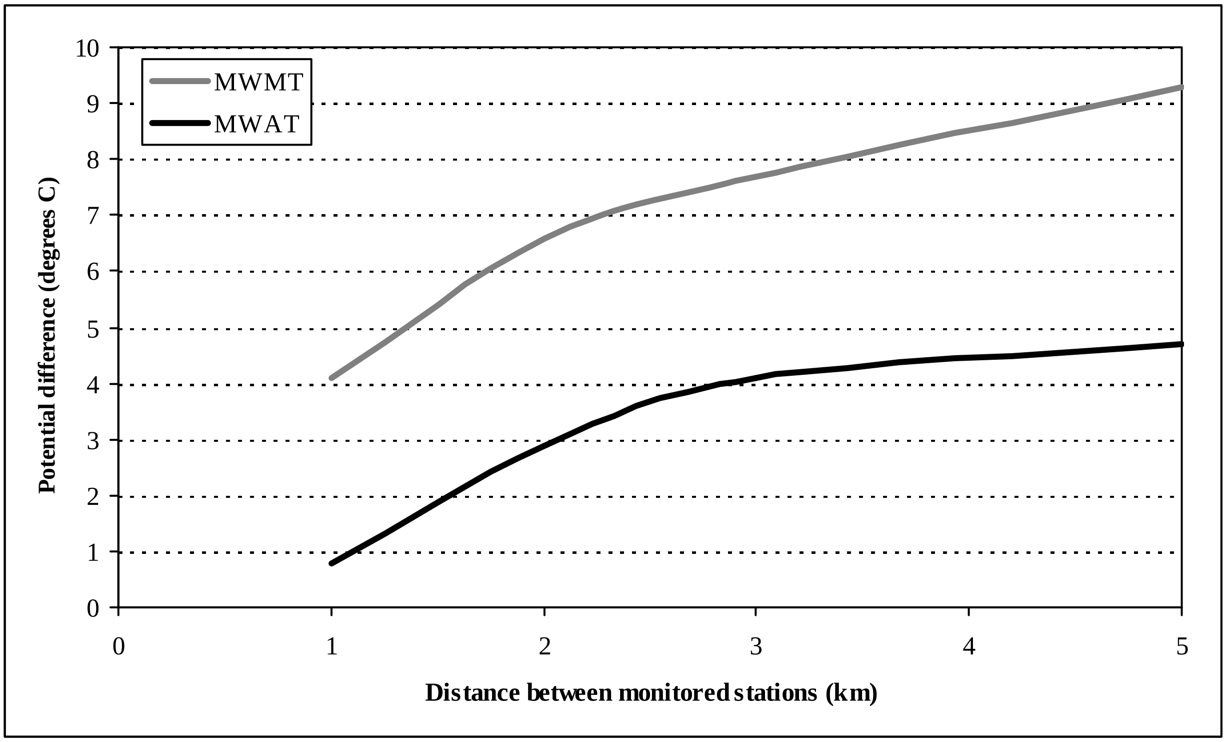

*Figure 1. Potential (maximum) within-year differences in maximum weekly average temperature (MWAT) and in maximum weekly mean maximum temperature (MWMT) between two locations on a given Western Oregon stream, per monitoring of 10 stations on tributaries to the Mohawk River, Oregon, 2003-2005 (Data source: Huntington 2006).*

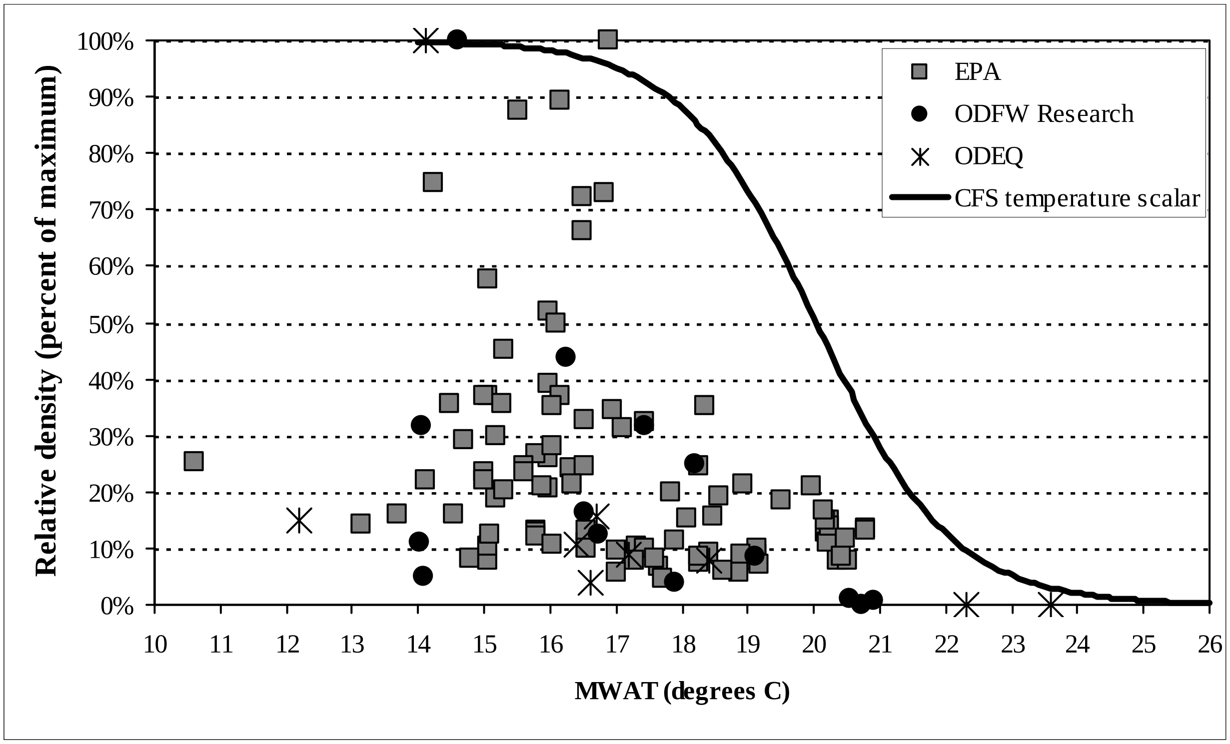

*Figure 2. Relative densities (abundances) of coho salmon parr versus maximum weekly average temperatures (MWATs) at 53 western Oregon stream locations sampled for both fish abundance and water temperature during summer, 2002-2005 (Data sources: J. Ebersole, EPA, Corvallis, OR, pers comm.; D. Jepsen, ODFW, Corvallis, OR, pers comm.; A. Borisenko, ODEQ, Portland, OR, pers comm.). Note: relative densities within each dataset were scaled to the highest observed density within the set.*

## Incorporating Kamath R. Disease Trends into the Life-Cycle Model (Technical Memo 6)

Per earlier comments, it seems that if possible the model should incorporate both the magnitude and duration of fish exposure to stressors. This would allow flow to affect disease incidence in at least two ways: fish migration rates and the water temperatures to which the fish are exposed. If flows were low enough to significantly slow out-migration, fish would be exposed to prevailing water temperatures for longer periods of time and a fish's prolonged presence in the river would probably expose it to higher temperatures than it would otherwise have experienced.

Is it safe to presume that a fish disease scalar will somehow be applied to the production of coho parr that spend more than a short period of time in the mainstem Klamath?

## Temperature and Flow Dynamics of the Klamath River (Technical Memo 7)

The detailed ability to simulate temperatures and flows in the Klamath River is going to be central to an effective coho model. The tools outlined in your memo make clear that you have at your disposal a very effective tool for this type of simulation. Two aspects of your potential use of this tool are not entirely clear in the memo but seem likely to be important to meaningful modeling: (1) making sure that any segments of the mainstem Klamath that you define as consistently being thermally unsuitable for the summer rearing of coho are based on simulations of natural (rather than diversion-modified) flow regimes, and (2) assuring model flexibility that allows one to identify the differing effects on coho (if any) of flow alterations during different types of water years. For example, Technical Memo 5 suggests that summer rearing in the mainstem Klamath outside thermal refugia is restricted to areas upstream of the Shasta River, but it is not clear to me whether the degree to which this limitation may be influenced by ongoing flow modifications has been taken into account.

## Loss of Redds to Gravel Scour (Technical Memo 8)

Eliminating in-river spawners from further consideration by the model would seem to assume that these fish are either a continuous drain on adjacent spawning populations or have no connection to those populations. It also seems to assume that the spawn timing and selection of redd construction sites by coho do not provide much buffer against the impacts of bed scour. I'm not sure which of these assumptions are valid, but doubt that mainstem spawners are unimportant to natural production unless all of the mainstem spawners are behaviorally deficient hatchery strays. Is it possible that these fish spawn near mainstem areas where there are good thermal refugia (either in the mainstem or in nearby tributaries) during summer? Regardless, it seems that the success of these mainstem spawners at producing offspring in at least some years may be important given the poor status of coho in the basin. Shouldn't the model account for them somehow, even if it is only to consider their potential contribution to adjacent spawning populations in some years or as a potential drain on these populations in others?

## CITATIONS

2006. Huntington, C.W. Aquatic monitoring in the Mohawk Watershed, Oregon. Consultant report to the Mohawk Watershed Partnership and the Bonneville Environmental Foundation. Clearwater BioStudies, Inc., Canby, Oregon. June 2006. [copy provided]

**Clearwater BioStudies, Inc.**

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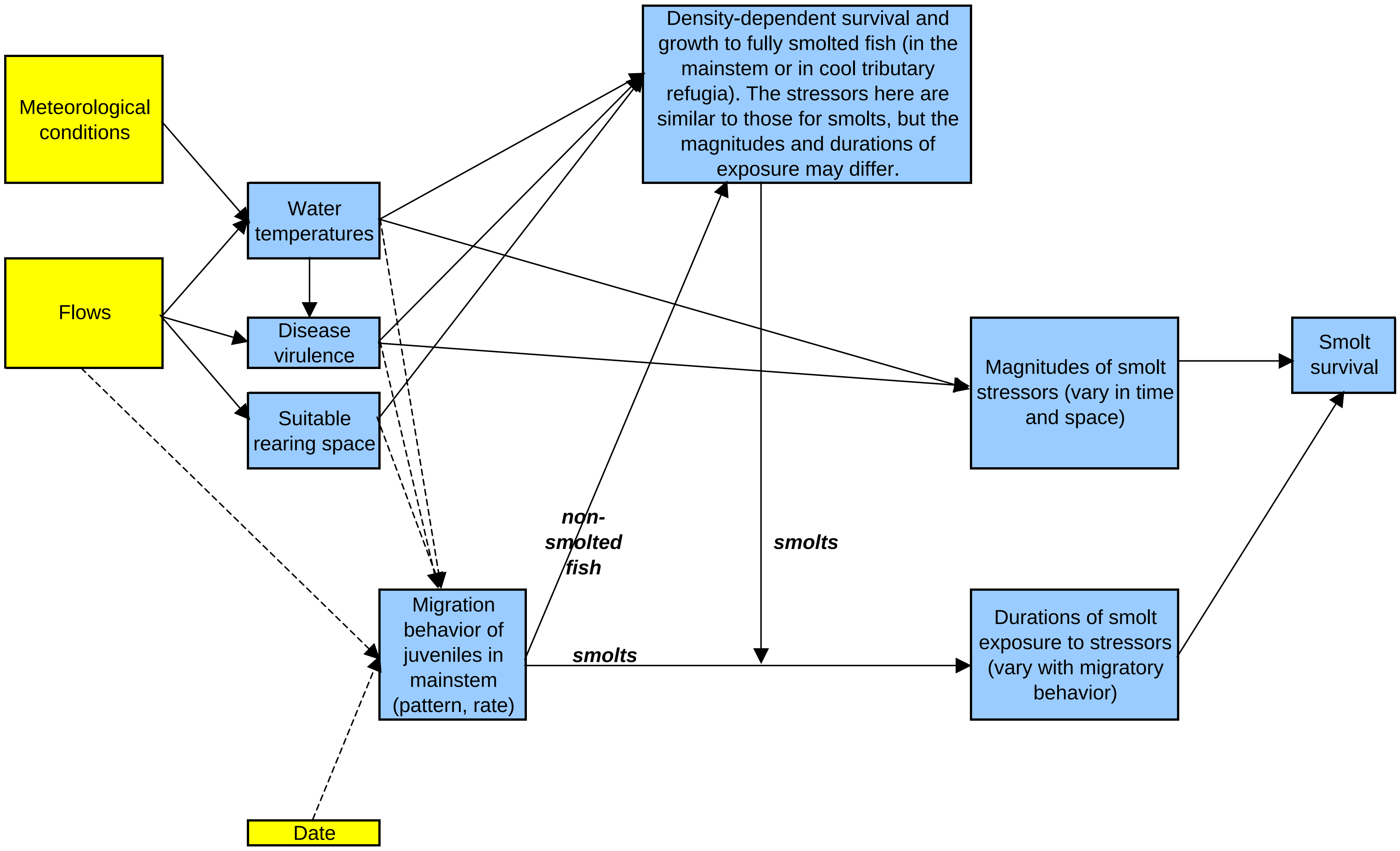
# TECHNICAL MEMORANDUM

To: Ian I. Courter, Cramer Fish Sciences
From: C.W. Huntington, Aquatic Biologist
Subject: Comments on the structure of the Klamath R. coho model
Date: 26 June 2007

Cramer Fish Sciences (CFS) has compiled much of the available information on Klamath coho and their habitat, and has made an effort to describe several of the functional (mathematical) relationships that are needed to model coho use of the mainstem Klamath. These efforts have been important and very helpful in clarifying the key issues that the model of Klamath River coho will need to address. However, my understanding is that scheduling and budget limitations may soon lead CFS to conduct model runs and sensitivity analyses using a model whose structure has not been vetted by the review group. This would be unfortunate, because the model's structure is likely to be as important to its performance as the multiple model components that have been subject to review. Rather than sticking to an optimistic schedule and achieving substantially less than might be possible, a better next-step in the model's development might be to have its structure vetted by reviewers so that there will be a reasonable level of confidence in the results of future model runs.

In my view, the portion of the CFS model that will simulate juvenile coho performance in the mainstem Klamath River should be structured on a consistent and short time-step (daily or perhaps weekly), and be flexible enough to provide outputs for the kinds of distinct water year types that are a mainstay of Klamath Basin planning. It should be driven primarily by the interaction of (1) streamflow and (2) meteorological conditions, with (3) date, or perhaps week, providing some level of influence on the migratory behavior of juvenile fish (Figure 1). These three driving factors, in combination with their known or hypothesized influence on water temperatures, on disease virulence in the mainstem Klamath, on rearing space, and/or on the migratory behavior of juvenile coho, should be used to estimate the magnitude, duration, and consequences of coho exposure to stressors as the fish progress toward reaching the estuary as smolts. Basically, the portion of the model simulating juvenile coho performance should have two critical components. One component should be a set of algorithms describing fish migratory behavior (pattern and rate) as influenced by environmental conditions, and the other a set of functions that define the consequences of each day (or week) a group of fish spends in a given part of the river system.

**Figure 1. Conceptual elements of modeling juvenile coho salmon in the mainstem Klamath.**



*Note: dashed vectors identify relationships that might (or might not) be incorporated into a variety of modeled hypotheses about fish behavior.*

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# TECHNICAL MEMORANDUM

To: L.K. Dunsmoor, Sr. Ecologist, Klamath Tribes
From: C.W. Huntington, Aquatic Biologist
Subject: Review of Klamath Coho Life-Cycle Model
Date: 30 November 2007

## OVERVIEW

The following memorandum is based on an extended review of working versions of the Klamath Coho Life-Cycle Model (Cramer Fish Sciences [CFS] 2007) developed for the Bureau of Reclamation (BOR) and available documentation on this model. Per my contract with the Klamath Tribes, the memorandum is intended to help you develop an opinion on this model and to identify ways to make the model a reliable tool for helping managers make resource allocation decisions on the Klamath River. For almost a year I have been working with CFS staff and multiple other biologists trying to help develop such a model. It is my hope that the results of my review, including this memorandum, will continue to move the model in this direction.

Before stepping through a discussion of the Klamath coho model in its current configuration, it seems appropriate to clarify my perspective on this type of model and salmon modeling in general. Salmon models are always going to be imperfect simplifications of a complex reality, and each one is going to have strengths and weaknesses. The true test of such a model is not whether it meets some unattainable level of perfection, but whether (1) its logic is consistent with salmon ecology and available data, (2) population simulations exhibit reasonable behaviors that are at least not inconsistent with the observations of those biologists who know the actual populations best, and (3) the model is reasonably suited to its intended use. With regard to this third point, it is my understanding that the Klamath coho model is intended to evaluate the potential effects on Klamath coho of various management actions in the upper basin and particularly the management of water.

Per your request, my discussion here will begin by characterizing what I view as the model's utility, its relative strengths and weaknesses, and what (if any) additional steps might need to be taken before model outputs should be relied upon for decision-making. My thoughts on each of these issues are tempered by a sense of what can reasonably be expected of a salmon model, as described in the preceding paragraph.

- **Model utility.** The utility of the Klamath coho model (as made available during November 2007) is strongly influenced by the model's basic structure, the functional relationships that drive coho performance within the model, and the model's potential for future refinement as new data on these fish are collected. Because the model is deterministic and highly parameterized, it depends on a substantial number of inputs and relationships for which site-specific empirical information is very limited. At present, many of these inputs have been either (1) derived by the model's developers using a variety of analytical methods and information sources or (2) amount to educated guesses that can be adjusted by the model user. The effort that has gone into assembling information and incorporating it into the model has been substantial, and is reflected in some clever elements of model construction. The model's internal architecture is complex but transparent, something that will help modelers, biologists, or others identify ways to improve its performance.

  The structure of this model raises a couple of issues that may be worthy of note. First, it is driven by temperature-flow modeling for only three specific water years (2001 [dry], 2004 [average], and 2006 [wet]), and although users can input specific alternate flow regimes to what occurred in those years, the modeled effects of the alternate regimes will depend on user selection of conditions for one of these three years to set daily release temperatures at Iron Gate and the daily volume and the temperatures of major tributary inputs. This may limit future model refinements based on hind-casting techniques as well as use of the model as anything more than a general tool for informing management decisions. My thinking several months ago was that this model could have been driven by site-specific statistical models of meteorology-flow-temperature relations based on long-term records from weather stations and stream gauges. As constructed, year-specific tributary inputs and year-specific release temperatures from Iron Gate Dam will only be available to model users if the BOR and its consultants (1) use the underlying water quality model to produce a larger number of flow-temperature input files for the model or (2) site-specific statistical models as just described are somehow incorporated into the model as a "user option".

The model is structured primarily to address basic management decisions related to river flows (and temperatures) and how they affect Klamath coho. It is not equipped to examine questions about the potential influence of past or ongoing upper basin activities (whatever they might be) that might affect coho by altering nutrient dynamics or the general ecology of salmonid diseases in the 300+ km of Klamath River downstream of Iron Gate Dam. The model is also, at least in its present configuration, focused on areas below Iron Gate and would thus require modification before it could be used to answer questions about how management actions might affect potential salmon performance above that dam.

- **Strengths and weaknesses.** The strengths of the model are that it is relatively transparent, provides a coherent structure for beginning to evaluate the effects of Klamath River management decisions on coho salmon, allows for a variety of user-based adjustments to inputs, and packs a surprising amount of important information into a fairly tight space. Several aspects of the model's construction are impressive. However, the model does have some important weaknesses, the most critical of which is a smolt survival function (see the SMOLT EMIGRATION SURVIVAL section of this document) that is central to how the model operates but that performs poorly and does not appear to produce reliable output.

- **Next steps.** My sense, though I am clearly no decision-maker here, is that making this model something reliable for use in public decision-making is going to require three things. First, a serious effort to incorporate many of the improvements suggested in this memorandum as well as additional improvements that may be identified by other reviewers during this cycle of model refinement. Second, the model's developers and reviewers should have another work session to fine-tune and examine whatever changes are made to the model, including a serious group effort at fixing the smolt survival function that is at the center of the model. Finally, it would be helpful to have a substantial number of additional flow-temperature data files developed for use as model input, based on actual data for water years not already included in the model. This last step should probably be coupled with a request for the timely development of more such files in the future, so that the model can be continually upgraded to fit available information on smolt emigration survival and other key modeled parameters.

The remainder of this memorandum provides many (but far from all) of the details of my model review, and provides abbreviated comments on specific sections of the draft Model Report (CFS 2007). It begins by clarifying some issues related to flow regimes and also by identifying the locations of specific river reaches that are referenced at various places in the text, figures, or tables that follow. The memorandum then steps through comments on specific aspects of the CFS model in approximately the same sequence they are addressed in the draft Model Report.

### ***Flow regimes***

In order to help place model behaviors and the results of recent coho modeling in what for me was a helpful context, I used a variety of analyses by others to construct "natural" 20%, 50%, and 80% exceedance annual hydrographs for the Klamath River at Iron Gate Dam (Figure 1). These hydrographs, based on the combined work of Hecht and Kamman (1996), Cooper (2004 and pers comm.), and the BOR (2005), were not intended to be the final word on the issue of natural flows in the river, as I am well aware that this is a topic of substantial debate. Nor were they intended to represent an exact estimate of the effect that the Klamath Irrigation Project has had on lower river flows, or on how coho performed below Iron Gate Dam prior to development of the basin. Both the upper and lower portions of the Klamath basin have been substantially altered (NRC 2004) and it is not clear to me whether the ecology of disease-causing pathogens, altered hydrologic functions throughout the system, or other factors, have changed the degree to which coho in the lower basin are sensitive to changes in flow. It does seem relatively clear, however, that modifications to the basin (of many types) have reduced late spring and summer flows at Iron Gate Dam and that the Klamath River environment below the dam is not particularly good for anadromous salmonids during a significant portion of the year. Placing model-based analyses in a historical context seems likely to be informative when considering incremental flow improvements that simple logic (without the aid of a model) suggests are likely to be incrementally helpful to coho.

Elsewhere in this memorandum, I will sometimes refer to three classes of archetypal water years: (1) "Dry" years with 2001 tributary inputs to the mainstem Klamath and 80-percent exceedance releases at Iron Gate Dam, (2) "Average" years with 2004 tributary inputs and 50% exceedance releases, and (3) "Wet " years with 2006 tributary inputs and 20% exceedance releases. For each class of year, I will sometimes also identify the flow releases at Iron Gate as reflecting "natural", "post-Iron Gate Dam" (post-IGD), or "proposed" flows. The release flows used for "natural" conditions were as shown in Figure 1. Release flows for each water year type under post-IGD or proposed conditions were those already incorporated by CFS into their coho model.

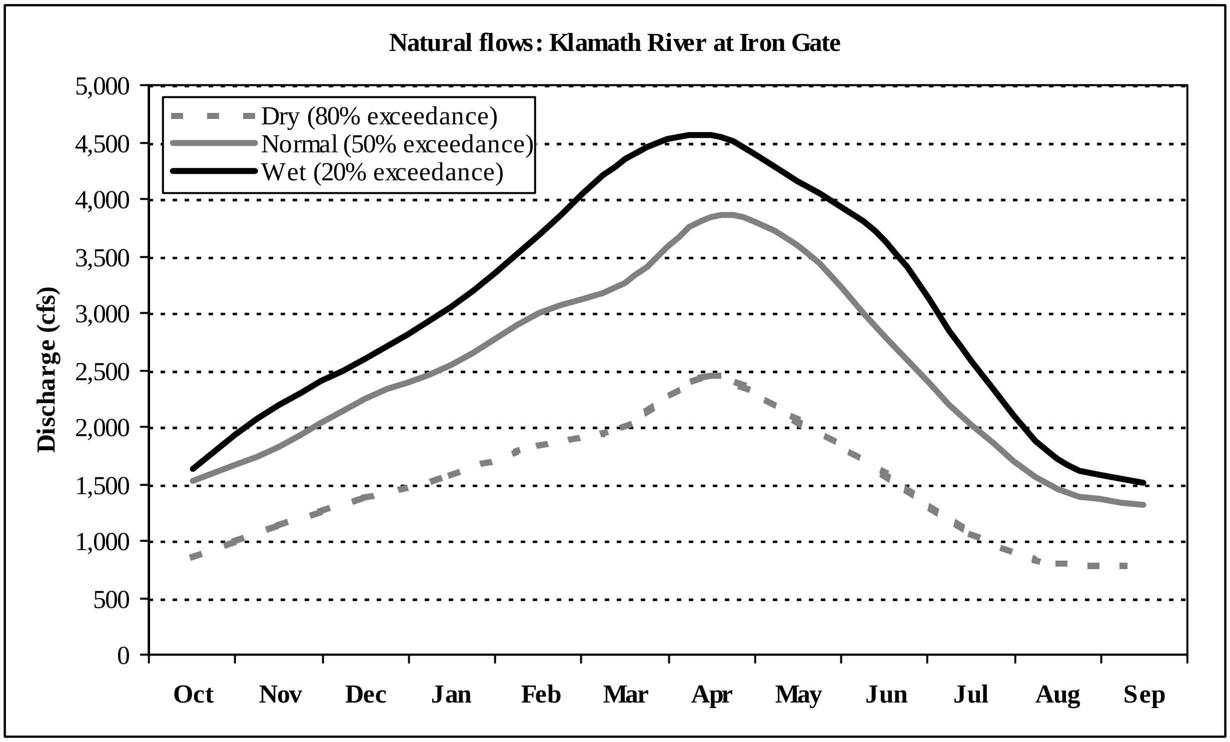


***Figure 1. Rough estimates of pre-developed, unaltered hydrographs for the Klamath River at the current site of Iron Gate Dam (data sources: Hecht and Kamman 1996,Cooper 2004, Cooper pers comm., and BOR 2005).***

### *River reaches*

There will be multiple references to specific reaches of the Klamath River in this memorandum. These reaches, as defined by CFS (2007), are as follows:

MS1 – Iron Gate Dam to Shasta River
MS2 – Shasta River to Scott River
MS3 – Scott River to Portuguese Creek
MS4 – Portuguese Creek to Salmon River
MS5 – Salmon River to Trinity River
MS6 – Trinity River to Mouth

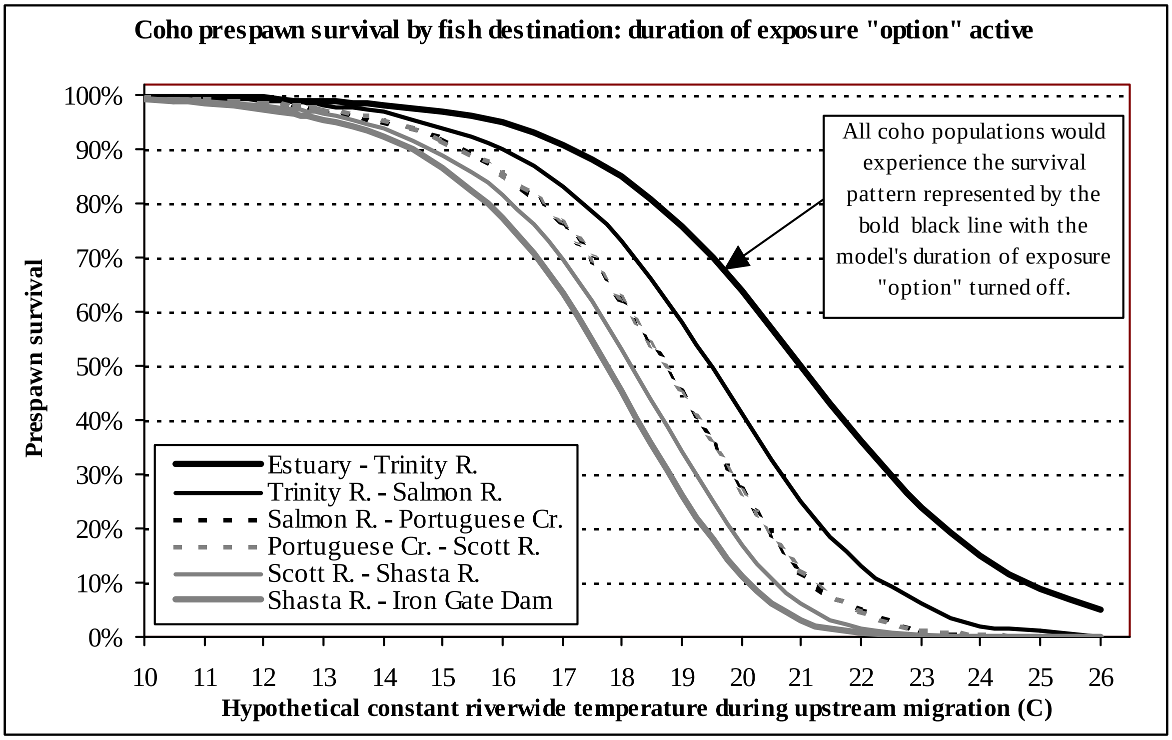
## MODEL COMPONENTS: SPAWNER SURVIVAL (CFS 2007; pages 9-15)

The 07 November 2007 version of the Klamath coho lifecycle model (hereafter "the model") assumes specific and different temporal patterns for the upstream migrations of adult coho moving up the mainstem Klamath to spawn in the river's differing tributaries. These patterns are based on available information and appear reasonable to me given what I know about the river's coho. Given the presumed timing of the adult runs to differing areas within the basin, the model calculates the migration-related mortality of weekly cohorts of adult fish by applying a pre-spawn survival scalar as described below.

The default pre-spawn survival scalar in the November 2007 model is driven by fish exposure to mean weekly temperatures within river reaches and a logistic function with 95% fish survival at 16$^{o}$C and 5% survival at 26$^{o}$C. This scalar seems about right to me at the cooler end of the temperature spectrum but overly optimistic at the very upper end, though temperatures this high may not be experienced by coho in the Klamath given their run timing. The available literature suggests that upstream migrations of adult salmon can be blocked by mean water temperatures above the 20-22$^{o}$C range, so exposures to temperatures higher than this during migration may be unlikely. If the model consistently moves fish through temperatures this warm based on rigid migration timing (something I did not have the time to check), it seems likely to produce mortalities in areas that may not be reached by adult migrants.

Perhaps the biggest issue related to how the model estimates pre-spawn survival for weekly cohorts of adult coho returning to their natal streams is that in its initial configuration (i.e., in October 2007) it did not account for potential duration-of-exposure effects related to high temperatures. I commented on this issue during a meeting with the BOR and Cramer Fish Sciences (CFS) in Medford, and suggested the model be changed to take a duration-of-exposure (DOE) approach by compounding (multiplying) weekly pre-spawn survival rates the scalar generates for fish migrating up the river rather than simply taking a "worst-week" approach to estimating survival. The proposed DOE approach has been added as an "option" in the latest model from CFS, but the original, worst-week approach found in the initial configuration remains the default "option". There may be reasons for this that remain unexplained, but my sense is that the DOE approach should be the default option at a minimum or be hard-wired as the model's only option unless it proves impossible to figure out how to adjust the scalar to yield realistic output using this approach. At present, the default "option" takes the highest mean weekly temperatures each cohort of adults encounters along the mainstem Klamath and uses them to apply the survival scalar just once to determine a cohort's pre-spawn survival rate.

Being less familiar with Klamath coho than some reviewers, my latest contribution to refining the pre-spawn function has been to plot out mortality patterns evident in the model so that others might judge the need for additional changes. My first plot (Figure 2) was derived by hard-setting the entire river to a series of 1°C incremental increases in constant temperature for the full upstream migration period, just to see how the DOE approach and default pre-spawn scalar interact to affect spawners returning toward different natal tributaries. The model assumes a rate of fish travel that translates into one-week differences in DOE between adjacent curves shown in the plot. The survival patterns generated by the model suggest to me that the default pre-spawn scalar may need adjustment at the lower temperature end to work properly with the DOE setting.



All coho populations would experience the survival pattern represented by the bold black line with the model's duration of exposure "option" turned off.

***Figure 2. Model-estimated pre-spawn survival for adult coho returning to home streams tributary to specific reaches of the mainstem Klamath River, if there were constant river-wide temperatures during fall. River temperatures are not constant during the upstream migration period, but these plots make the influence of logic within the 07 November version of the lifecycle model explicit.***

When actually applied in the coho model, the pre-spawn survival scalar has an influence on adult fish that varies between water years and that is stronger with the DOE "option" active than it is when the user chooses not to consider the potential influence of DOE effects. Model behavior for Shasta River coho pre-spawn survival in each of three archetypal flow year types (see page 4), with the DOE "option" active or off, is shown in Figure 3. As might be expected, the model predicts pre-spawn survival that is higher in years of greater runoff and lower with the DOE "option" active than when DOE is not considered. Figure 4 depicts model behavior that suggests higher levels of pre-spawn mortality for sub-populations of coho destined for Klamath River tributaries between the Shasta and Salmon rivers than for other sub-populations.

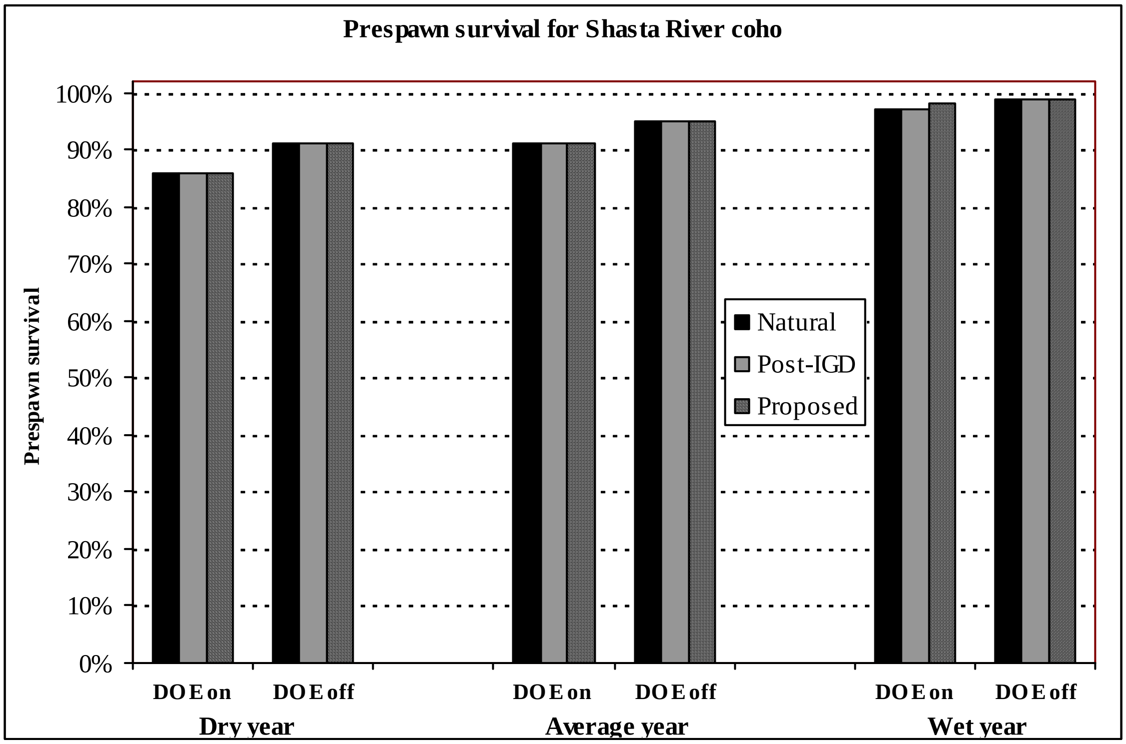


*Figure 3. Model-based estimates of pre-spawn survival for adult coho populations returning to the Shasta River, for differing flow regimes and water year types, with the duration-of-exposure "option" active (DOE on) or off (DOE off). These plots make the influence of logic within the 07 November version of the lifecycle model explicit for this coho population.*

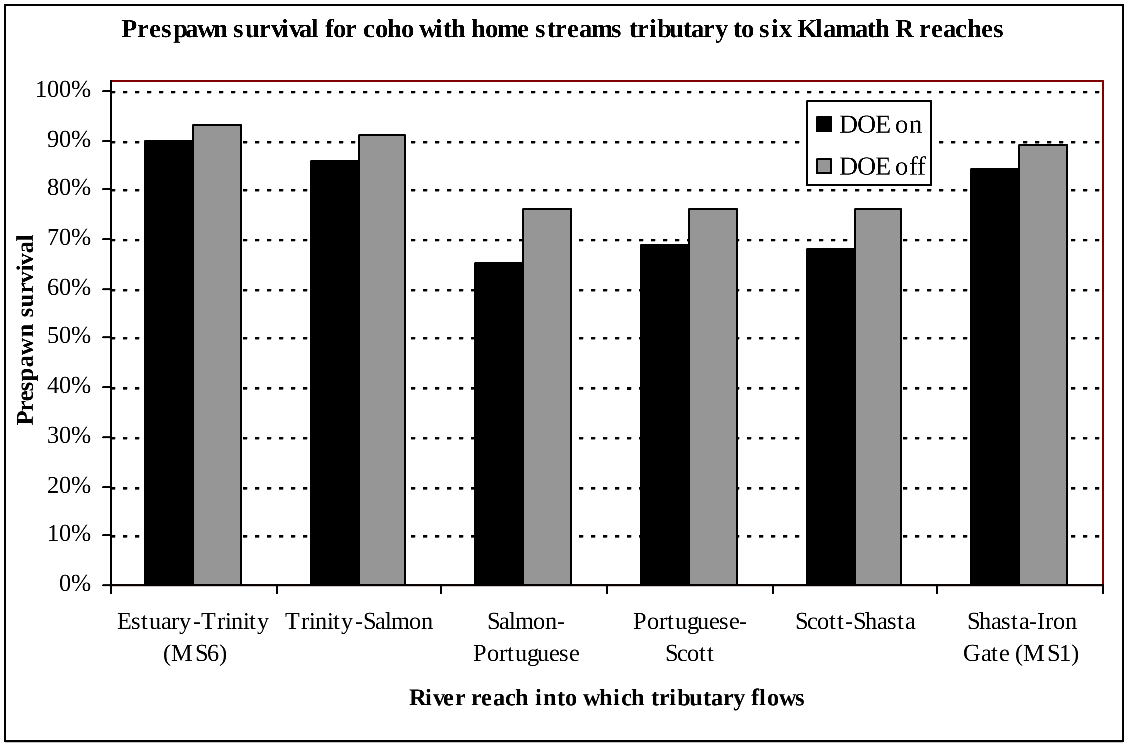


*Figure 4. Model-estimated pre-spawn survival for adult coho populations returning to home streams tributary to six Klamath River reaches during a Dry-type year, with the duration-of-exposure "option" active (DOE on) or off (DOE off). Mortalities of adult coho are affected in the model by a temperature-driven survival scalar, variable thermal regimes in the river, and model-assumed timing of the upstream migrations of adult fish.*

## MODEL COMPONENTS:  SMOLT PRODUCTION (CFS 2007; pages 17-36)

The Klamath coho model reflects and incorporates an important compilation and synthesis of available information related to the potential for widely dispersed streams in the Klamath basin to produce coho smolts.  In some cases this information is less detailed than might be desired, but it is what is available, and its use reflects a good deal of effort by the biologists on the Cramer Fish Sciences team.  They have made efficient and clever use of the available habitat information so as to couple the basin's streams and their coho populations with modeled environmental influences in the mainstem Klamath.  This aspect of the coho model's structure is a particularly important and very helpful piece of work.  However, it appears that this work could use adjustments in several areas, as described below.

### *Temperature-based rearing capacity scalars*

Per comments made to Cramer Fish Sciences in June (Huntington 2007) and on multiple occasions since that time, I have not seen reliable empirical information supporting the model's use of a 16-23$^{o}$C scalar as the default for streams like the Klamath's less productive tributaries. For example, the analysis summarized on page 20 (in text and within Figure 15) of the latest draft Model Report (CFS 2007) is based on "linked" temperature logger and coho abundance data may be from sites up to 2km from each other, introducing MWAT estimation errors at individual "locations" that could be as great as 3$^{o}$C (Huntington 2007).  A scalar that left few juvenile coho in such streams wherever the maximum weekly average temperature (MWAT) exceeded about 21or 22$^{o}$C would be far more consistent with available data, my own field experience, and the published literature.

CFS's 16-23$^{o}$C rearing capacity scalar may or may not be appropriate for coho attempting to rear in the mainstem Klamath without aid of thermal refugia.  Absolutely definitive information on this issue seems to be lacking.  However, and while acknowledging that duration-of-exposure issues might be influential here, the dependence of the river's juvenile coho on such refugia when daily temperature maxima exceed about 22-23$^{o}$C (Sutton et al. 2007) suggests that these fish do not have the thermal resistance suggested by the scalar, even with the Klamath's abundant food resources.  My sense is that the region of the scalar representing about 95% of thermally optimal rearing capacity should shift to the right of 16$^{o}$C with elevated food resources, but that the limits of tolerance for juvenile coho without thermal refugia may still be found where weekly average temperatures reach about 21-22$^{o}$C.  I will defer on this issue to the biologists who know best how these fish are using the mainstem Klamath at present, but the use of such high temperatures (if it is actually occurring without refugia) astounds me unless it is in fact a short-term occurrence ultimately constrained by the cumulative effects of extended thermal exposures.

### *Alkalinity scalar*

The model includes an option for the use of an alkalinity scalar to adjust the capacity of the Klamath River and its tributaries to rear juvenile coho so as to account for the fact that the baseline fish densities used to estimate carrying capacity came from outside the Klamath system. This seems a good idea. The scalar included in the latest model distributed by Cramer Fish Sciences is based on Ptolemy's (1993) work with salmonids in general but not his analyses focused specifically on the relationship between stream productivity and juvenile coho. Ptolemy's (1993) analyses of coho in western British Columbia suggest the use of a different alkalinity scalar ($ALK^{0.4}/3.83$) in the Klamath coho model. This coho-specific scalar would typically adjust rearing capacities to levels within 5-10% of those obtained using Ptolemy's more general relationship for all salmonids, but could help narrow a modeling uncertainty.

### *Thermal duration-of-exposure (DOE) effects on summer rearing capacity in the mainstem*

Conditions in the mainstem Klamath can be thermally unfavorable for salmonids over extended periods (Dunsmoor and Huntington 2006, many others). This makes accounting for the duration of coho exposure to warm water during summer an important when modeling the ability (or inability) of these fish to persist or thrive in the river. I proposed a DOE approach to addressing this issue in October, and CFS has since incorporated it into the model as a user option.

The DOE approach taken in the model is based on a "family" of five closely related temperature scalars that each reflect an $0.5^{o}C$ reduction in coho thermal resistance (a left-ward shift in the 5% abundance level) as the duration of fish exposure to high temperatures increases (Figure 5). The theoretical basis for these scalars is a relationship that Wehrly et al. (2007) found between salmonid abundance and mean stream temperatures, as well as experiments (e.g., Selong et al. 2001) showing the same general pattern of thermal resistance when salmonids are tested in a lab. For each modeled reach of the Klamath, mean daily temperatures for spring through fall are evaluated for their maximum mean 7-d, 14-d, 21-d, 35-d, and 56-d temperature by examining a series of rolling averages. Each of the five maximum means is then be applied to the scalar ("family member") specific to its respective duration of exposure, and the minimum of the five resultant scalar values then applied to the stream or reach of interest to determine the percentage of thermally optimum rearing capacity that is present.

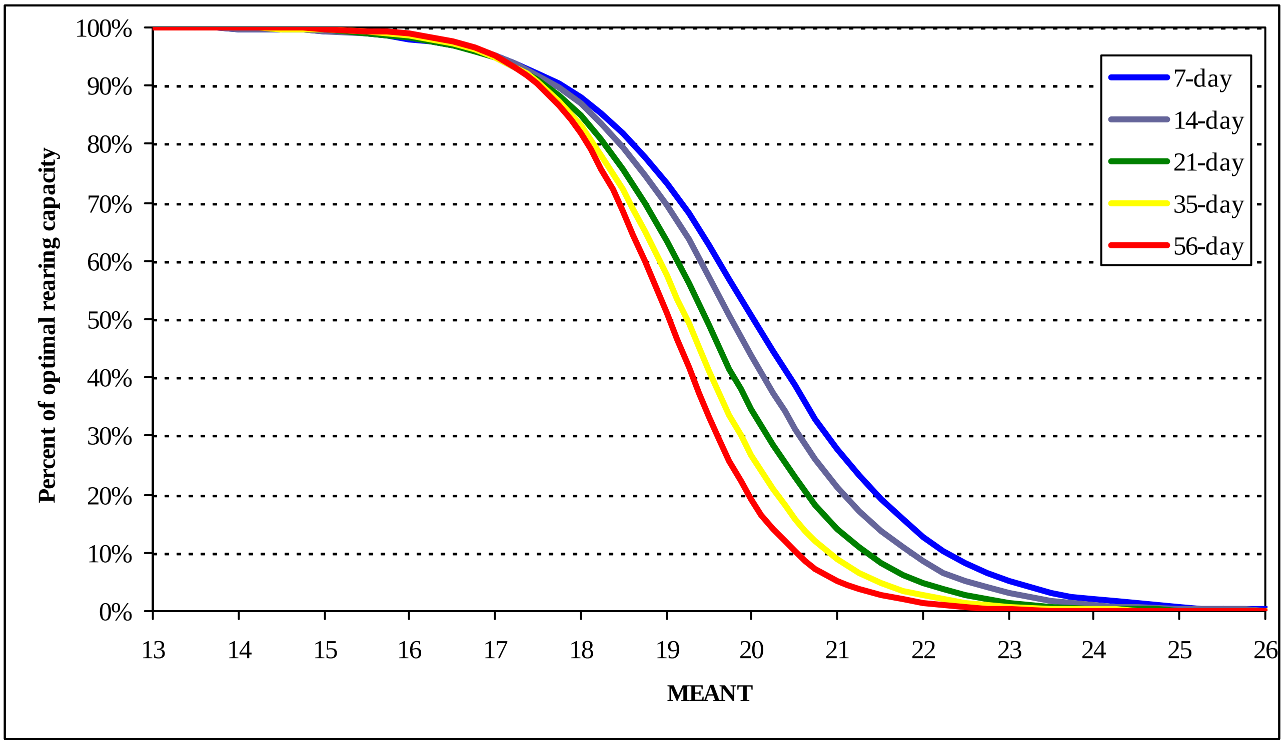


***Figure 5. Example set of five rearing scalars intended for integrated use in capturing thermal duration-of-exposure effects on coho parr capacity in the mainstem Klamath River. This particular set is derived from a primary scalar (in blue) that has 95% of optimal capacity at an MWAT of 17°C and 5% at an MWAT of 23°C.***

The approach just described for applying temperature scalars to estimate the rearing capacity of the mainstem Klamath is a workable but imperfect solution to a difficult problem: how to model thermal DOE effects on coho rearing in a stressful to potentially lethal environment without explicitly including consideration of reduced fish survival during summer. The approach leaves open the possibility that within the model small numbers of coho might persist at cumulatively lethal temperatures. However, given the probable use of the model, this flaw would probably be serious only if users lost sight of the fact that the model's outputs are not reality.

Model behaviors resulting from the interaction of temperature-based rearing capacity scalars and of IFIM-based estimates of coho rearing capacity in the mainstem reaches where it has been suggested these fish might, at least in some years, survive through summer away from thermal refugia (e.g., in MS1 and MS2) are highlighted in Figures 6-8. The behaviors shown are those that struck me as potentially of interest to other modelers based on comments at meetings that have been held in Medford, Oregon. Figures 6 and 7 show how river temperatures affect model performance with the DOE "option" either active or off, assuming summer-long constant water temperatures. Figure 6 gives the pattern of change in parr capacity for different river temperatures. Figure 7 gives the pattern of change in smolt production potential (which reflects a lagged over-winter effect from summer growth as well as changes in the model's simulation of

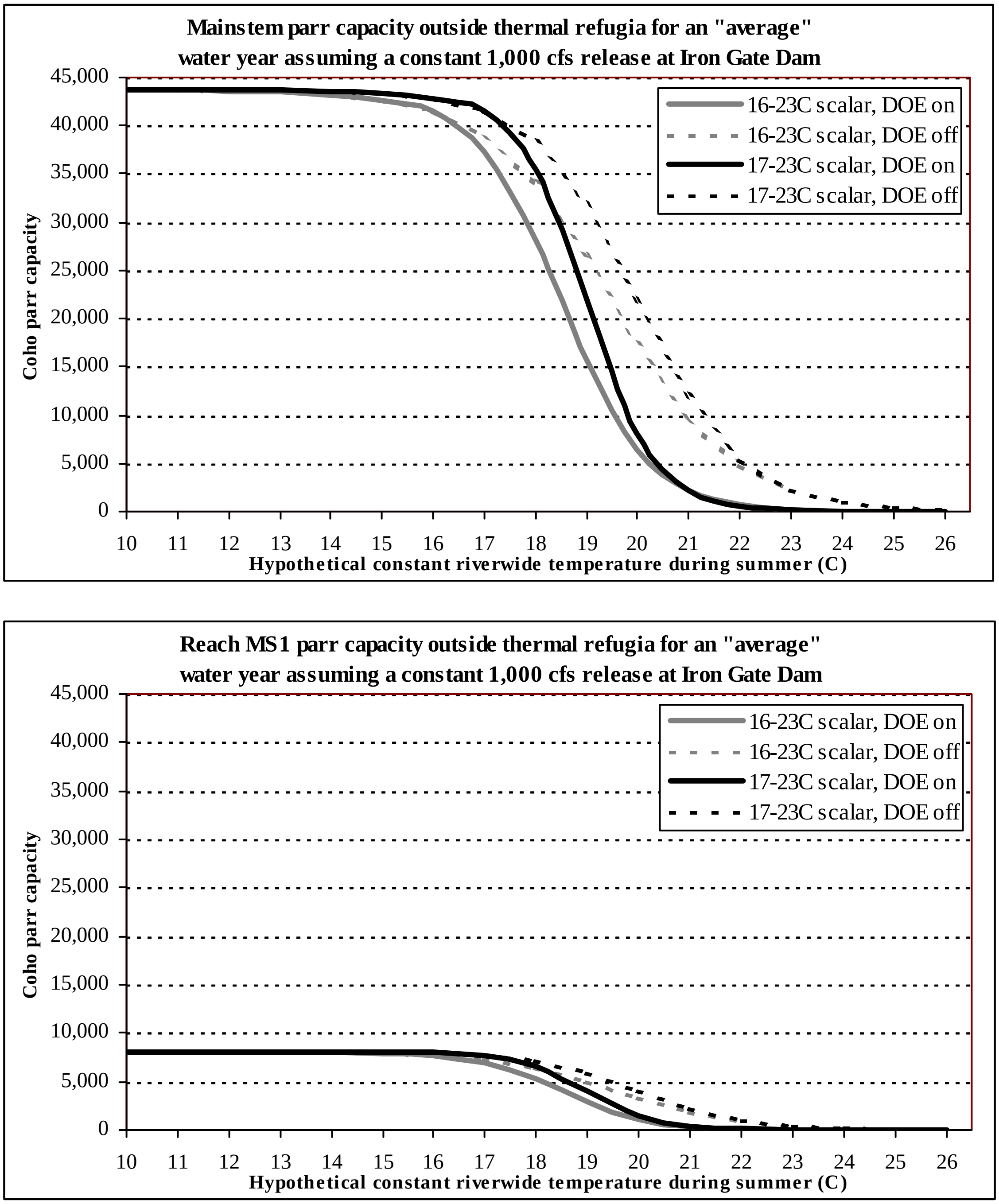
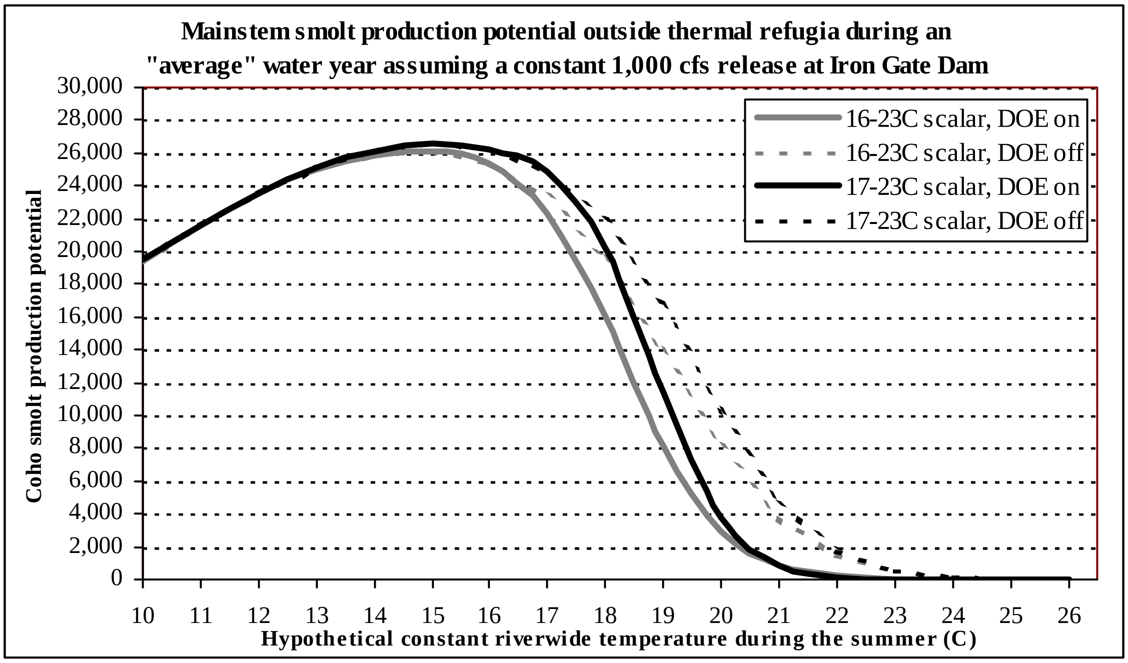


***Figure 6. Model-estimated summer capacity for coho parr rearing <u>outside</u> thermal refugia in the mainstem Klamath (reaches MS1 and MS2; top) and in reach MS1 alone (bottom), assuming constant river-wide temperatures during summer, alternative rearing capacity scalars, and with the duration of exposure "option" active (DOE on) or off (DOE off). Summer-long and river-wide temperatures are never constant during summer, but these plots make the influence of interacting logic within the November 2007 model explicit.***



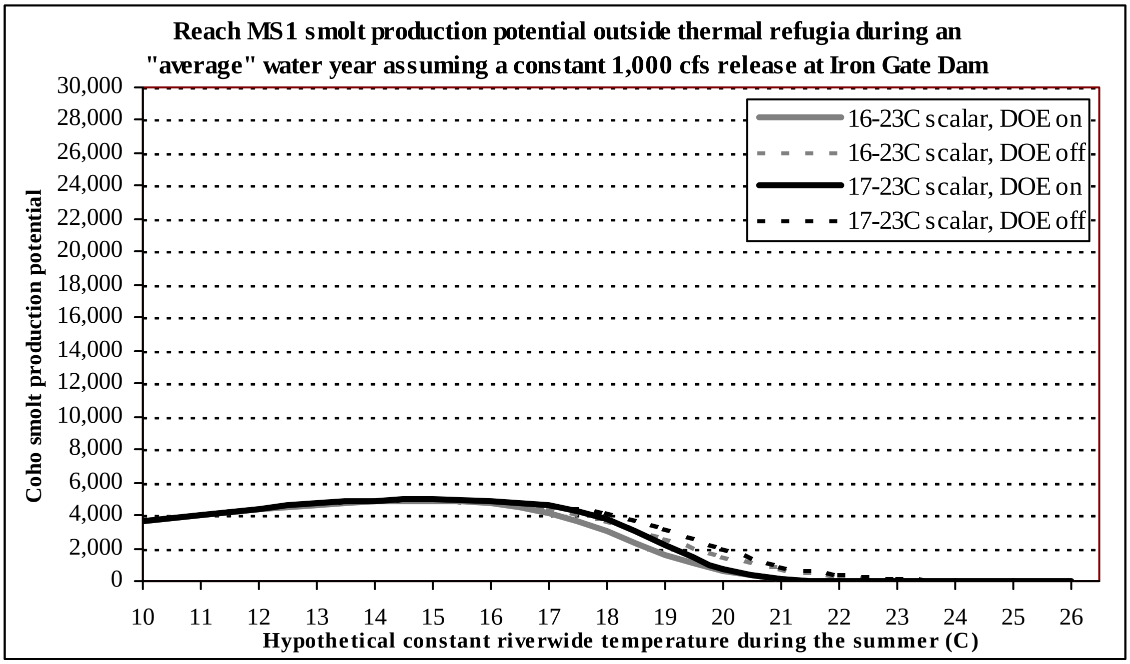
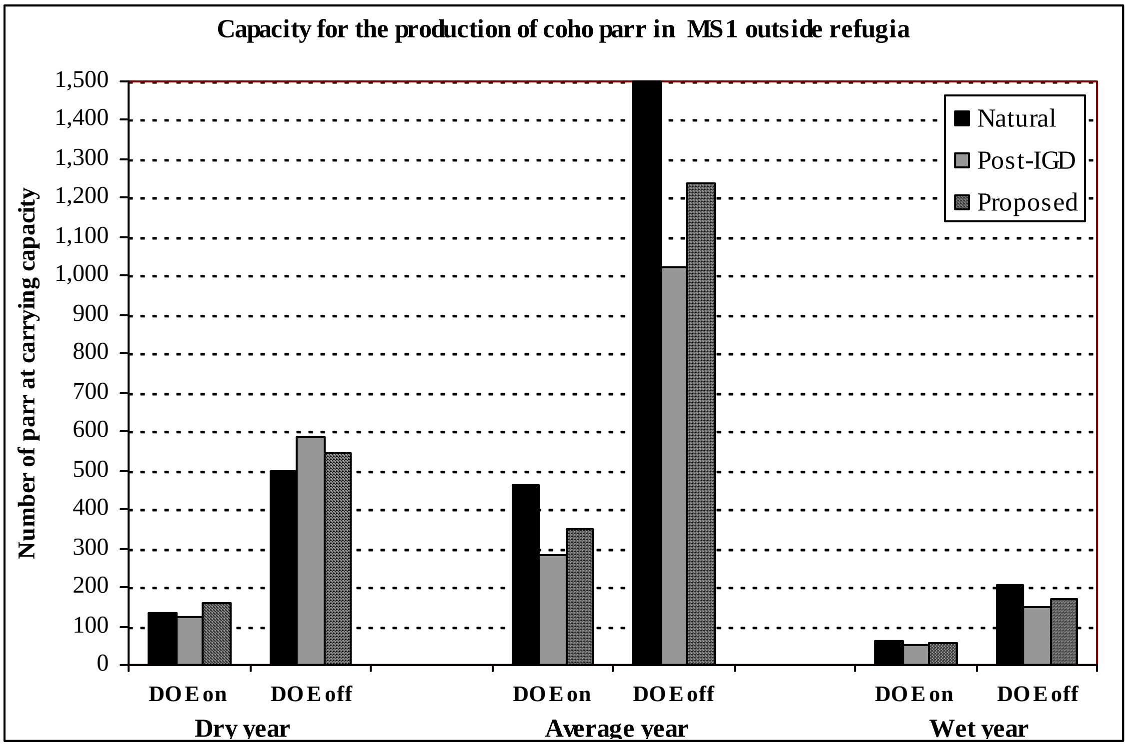


*Figure 7. Model-estimated smolt production potential for coho <u>outside</u> thermal refugia in the mainstem Klamath (reaches MS1 and MS2; top) and in reach MS1 alone (bottom), assuming constant river-wide temperatures during summer. Summer-long and river-wide temperatures are never constant during summer, but these plots make the influence of logic within the November 2007 model explicit.*



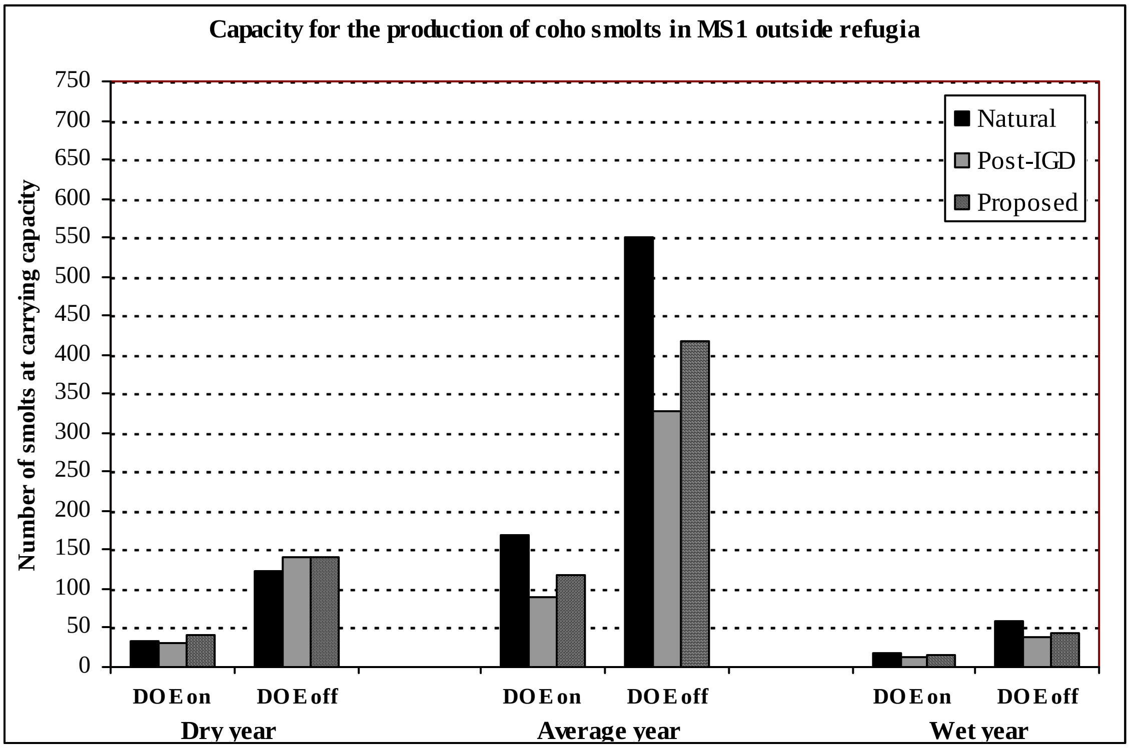


***Figure 8. CFS model-estimated capacity for the production of coho parr (top) and smolts (bottom) in reach MS1 of the mainstem Klamath river <u>outside</u> thermal refugia, for three water year types and three differing flow regimes, using the default 16-23$^o$C temperature scalar (and its DOE "family" of closely related scalars).***

parr capacity). Figure 8 shows how alternative rearing capacity scalars, and having the DOE "option" either active or off, might affect the model's estimates of summer parr capacity and smolt production potential in reach MS1 during the archetypal Dry, Average, and Wet years.

Given what the model predicts as the potential coho rearing response to some of the thermal exposures plotted in Figures 6-8, my conclusion is that model outputs are unrealistic with the new thermal DOE "option" turned off. Reflecting on studies, and other model components, that suggest high rates of disease-related smolt mortality in the mainstem Klamath downstream of the Shasta River (i.e., below reach MS1) during late spring, CFS may also want to revisit the question of whether juvenile coho are actually going to survive a full summer in reach MS2.

### ***Redistributions of fry and fingerlings within the model***

The Klamath coho model redistributes fry and fingerlings from the river's tributaries to thermal refugia along the mainstem and into the lower ends of cool tributaries during summer. The model's default setting for the rates of loss (mortality) of young coho associated with this redistribution in the model are lower than I might expect, particularly if fish are redistributing at times when smolt mortality in the mainstem seems to be elevated by exposures to disease-causing pathogens. However, the model is flexible enough that the user can change the settings.

### ***Smolt production functions for the Shasta, Scott, and Salmon River systems***

Coho production and productivity in the Shasta, Scott, and Salmon systems were not as might have been expected when simulated using the earliest version of the lifecycle model. Anomalous model behavior caused by interactions between four separate functions led to overly optimistic results for the Shasta River, and were fixed by CFS staff following an October meeting in Medford and prior to release of the recent model. Another improvement I have proposed for the smolt production functions of larger tributary systems (like the Scott and Salmon) is based on the same methodologies used in development of the initial lifecycle model, but parses the drainage networks of these systems into individual streams with more variable levels of productivity (rather than leaving them as undefined parts of an unproductive aggregate). This was acknowledged as a good idea by the model's developers, but I was told that they did not have sufficient time to incorporate such changes. I have now made the appropriate changes to the model and posted them in a revised model available to CFS through my firm's website (http://www.canby.com/cwbio/html/reports.html).

The consequences of the changes in smolt production functions adopted for the Shasta, and of those proposed for the Scott and Salmon systems, are summarized briefly in Table 1. Population productivity at low coho abundance in the Shasta system was reduced to something more consistent with existing empirical information. The productivity of the coho populations in the Scott and Salmon systems became more variable among streams, with some streams less productive than suggested by the aggregate productivities applied to these areas in the initial model and other streams more productive than in the initial model. In all of these cases, the text of Cramer Fish Sciences' Model Report (CFS 2007) will need to be changed to reflect how the model actually functions.

***Table 1. Consequences of proposed changes to smolt production functions in the larger tributary systems between Iron Gate Dam and the Trinity River.***

| Tributary system | General form of smolt production function | Productivity (smolts produced per female at very low abundance) | |
|---|---|---|---|
| | | Initial (October) model | Proposed revisions |
| Shasta River | Hockey-stick | 541[a] | 113[a] |
| | Beverton-Holt (1.5x) | 811[a] | 169[a] |
| Scott River | Hockey-stick | 29 | 2-125 (median =26) |
| | Beverton-Holt (1.5x) | 43 | 3-187 (median=40) |
| Salmon River | Hockey-stick | 35 | 10-93 (median=55) |
| | Beverton-Holt (1.5x) | 52 | 15-139 (median=82) |

[a] – includes age-0 smolts unique to the Shasta River system.

The relatively high smolt productivity of the Shasta system within the model is partly attributable to the presence of unique, age-0 smolts that leave that system during late spring.

### *Smolt emigration timing*

The CFS model assumes that smolts within given parts of the Klamath River system emigrate each year according to a firm biweekly schedule. This simplification makes a variety of clever but complex calculations simpler than they might be otherwise and may reflect the degree to which such things can be modeled at present. However, it does overlook some natural and likely adaptive behaviors of juvenile coho that may be expressed as annually varying emigration timing. This simplification is certain to have an effect on the accuracy of the model's simulations, but the magnitude of this effect is unclear and would be difficult to quantify.

There is, however, at least one aspect of the model's smolt emigration schedule that ought to be changed. The unique age-0 smolts produced in the Shasta system (CFS 2007) have emigration timing that is not properly simulated by the model. These fish typically begin emigrating in late-May, but the model treats them as if their emigration timing is similar to that of the Shasta's age-1+ smolts, the bulk of which tend to migrate earlier in the spring. Since the age-0 smolts are estimated to account for a sizeable portion of the Shasta's annual smolt production, a pattern of aggregate emigration timing that reflects a combination of age-0 and age-1+ smolts seems more appropriate than the one for age-1+ smolts alone that is programmed into the most recently distributed model. The pattern of emigration timing the model assumes for the Shasta system, and an updated pattern that is more likely to produce a realistic simulation of the Shasta's coho population, are given in Table 2. The updated pattern, something the biologists most familiar with this population consider important (Bill Chesney, CDFG, pers comm.), has been incorporated into the adjusted version of the model that has been made accessible to CFS through my website.

***Table 2. Original and updated emigration timing for coho smolts (both age-0 and age 1+) entering the mainstem Klamath River from the Shasta River system.***

| Timing pattern | Portion of annual emigration during a given bi-week (identified by start date) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2/5 | 2/19 | 3/5 | 3/19 | 4/2 | 4/16 | 4/30 | 5/14 | 5/28 | 6/11 | 6/25 | 7/9 |
| original | 0.000 | 0.000 | 0.001 | 0.026 | 0.187 | 0.420 | 0.297 | 0.066 | 0.004 | 0.000 | 0.000 | 0.000 |
| updated | 0.000 | 0.000 | 0.001 | 0.018 | 0.126 | 0.283 | 0.200 | 0.044 | 0.328 | 0.000 | 0.000 | 0.000 |

## MODEL COMPONENTS: SMOLT EMIGRATION SURVIVAL (CFS 2007; pages 37-56)

CFS has incorporated into their model a set of three functions (baseline or "optimal" smolt survival per 100 km, a temperature-survival scalar, and reach-specific flow-survival scalars) in an effort to simulate how a variety of factors interact to influence the survival of coho smolts migrating down the mainstem Klamath River from a given point of origin to the ocean. Recent studies by Stutzer et al. (2006) and Beeman (2007; pers comm.) have begun to shed light on this issue, but much remains to be learned. Current understanding of the precise functional interactions between multiple factors influenced by river flows and coho smolt (or other juvenile salmonid) survival in the mainstem Klamath can be characterized as imperfect but improving rapidly as a consequence of ongoing and substantial research efforts by multiple parties. *Despite this research, however, available data on longitudinal patterns in smolt survival as these fish emigrate down the Klamath are restricted to smolts originating near the Shasta River or Iron Gate Fish Hatchery (IGH). We really do not know whether the longitudinal survival patterns of these fish are the same as those that begin their downriver migration at locations lower in the system.* This context makes the existing, highly complex set of smolt emigration functions driving the Klamath coho model something that may well be workable at some point in the future but that seems at present to have a high potential for producing spurious or misleading results.

After obtaining from CFS staff the underlying data and analyses behind the flow-survival scalars in their model, concern that the interacting functions within the current model could produce unreliable outputs turned to near-certainty that this is the case. The problem stems from a combination of the way in which the flow-survival scalars have been derived and the manner in which they are applied by the model.

The flow-survival scalars within the model were derived by a rough curve-fitting method in which an assumed functional form was "matched" to a small number of data points from smolt survival studies after those data were adjusted to account for a presumed "baseline" (optimal) survival rate. Annual adjusted, reach-specific survival estimates for coho smolts passing down the Klamath River from the IGH-Shasta River area toward the mouth during 2005, 2006, and 2007, were plotted against the median spring (March-May) flows experienced in the same reaches and years. The curves were then fit to the plots. There are two basic problems with this approach as it has been employed. First, even if the functional relationships so derived were reliable, they would seem appropriate only for estimating <u>annual</u> smolt survivals through a reach based on the median spring flows experienced in one or more specific years. The existing model applies these relationships to biweekly cohorts of smolts emigrating from the river. Second, the functional relationships that have been derived are not particularly good fits to the available data. In fact, they appear to be far from good fits if one assumes that for their derivation to be valid the flows upon which they are based need to have been those that occurred while the test fish during the underlying survival experiments were actually in the Klamath River. In my view, this would be a logical assumption since the functions are being applied to biweekly and not annual groups of smolts.

After acquiring data on the dates during which coho smolts involved in the 2005, 2006, and 2007 survival studies upon which Cramer Fish Sciences' flow scalars (CFS 2007) are based, I constructed a summary of the dates bounding the known presence of test smolts in each of the six river reaches being modeled. When these bounded dates were compared to the 01 March-May 31 bounds used in the analysis by Cramer Fish Sciences (CFS 2007), there were substantial differences. These differences affected calculations of the median flows that might be appropriate for curve-fitting (Table 3), as well as how well the functional relationships in the existing Klamath coho model fit the available empirical data (Figure 9).

***Table 3. Dates of known presence of tagged coho smolts from survival studies (data sources: J. Beeman, USGS, pers comm., G.Stutzer, USFWS, pers comm.) and median flows for dates bounded by the known presence of these fish, by river reach and year.***

| Klamath R. reach | Dates tagged coho present, by year | | | Median flow (cfs) bounded by dates, by year | | |
|---|---|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2,005 | 2006 | 2007 |
| MS1 | 3/28-6/10 | 4/4-6/4 | 4/10-5/29 | 1,530 | 4,495 | 1,610 |
| MS2 | 3/29-6/10 | 4/5-6/5 | 4/9-6/8 | 1,530 | 4,495 | 1,610 |
| MS3 | 4/23-6/14 | 4/24-7/2 | 4/14-6/17 | 4,210 | 6,910 | 2,820 |
| MS4 | 4/29-6/14 | 4/28-7/2 | 4/29-6/10 | 6,110 | 10,020 | 4,090 |
| MS5 | 4/29-6/14 | 4/29-6/17 | 4/30-6/13 | 13,500 | 17,800 | 5,500 |
| MS6 | 4/29-6/4 | 4/30-8/3 | 5/8-6/14 | 31,800 | 17,600 | 10,150 |

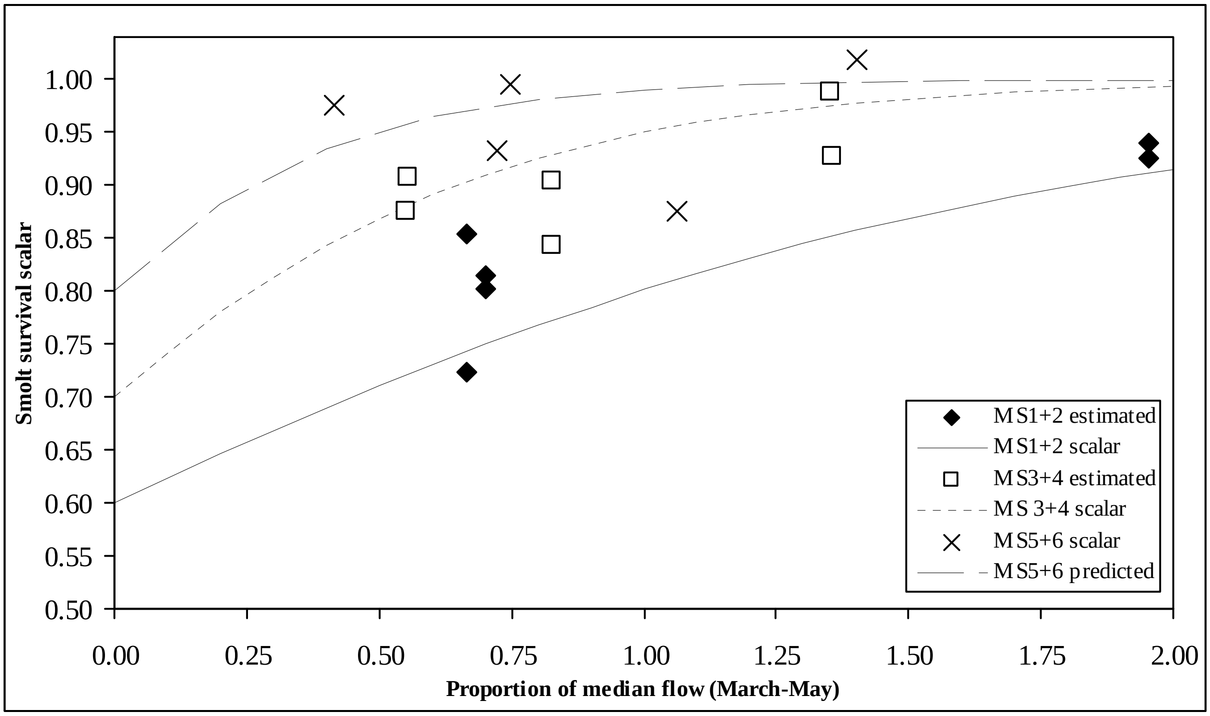


***Figure 9. Flow-based smolt survival scalars in the November 2007 model versus study data, if the annual reach-specific flow metrics were calculated as the fraction of 10-yr median spring (March-May) flows that were experienced during the period each year that test fish were actually known to be present in each reach.***

Since the model includes factors other than flow (i.e., a temperature-survival scalar), it occurred to me that the model might somehow overcome what appears to be the poor fit of the flow-survival scalar by making additional and substantial adjustments to its estimates of smolt survival. I tested this by, as best I could, using the model itself to predict coho smolt survival from Shasta River (near the point of entry for past smolt studies) to the ocean for the years in which survival studies have been conducted. This was done employing user options and my familiarity with the model to enter biweekly release flows at Iron Gate Dam for 2005, 2006, and 2007 into the model, matching tributary inflows as well as possible (actual 2006 inputs, "dry" year inputs for 2005, and "average" year inputs for 2007), and examining what the model predicted as to-ocean survival for coho smolts from the Shasta River. In brief, the model did not perform well and clearly seems to overestimate survival (Figure 10).

The poor aggregate performance of the flow-survival scalar and related model functions, at least in terms of predicting smolt survival, is a monumental problem within the existing model given that this is the most influential model element contributing to predictions of flow effects on coho in the Klamath. There are undoubtedly ways to address this problem (some of which will be discussed next), but it clearly needs to be fixed before anyone relies on model output for public decision-making.

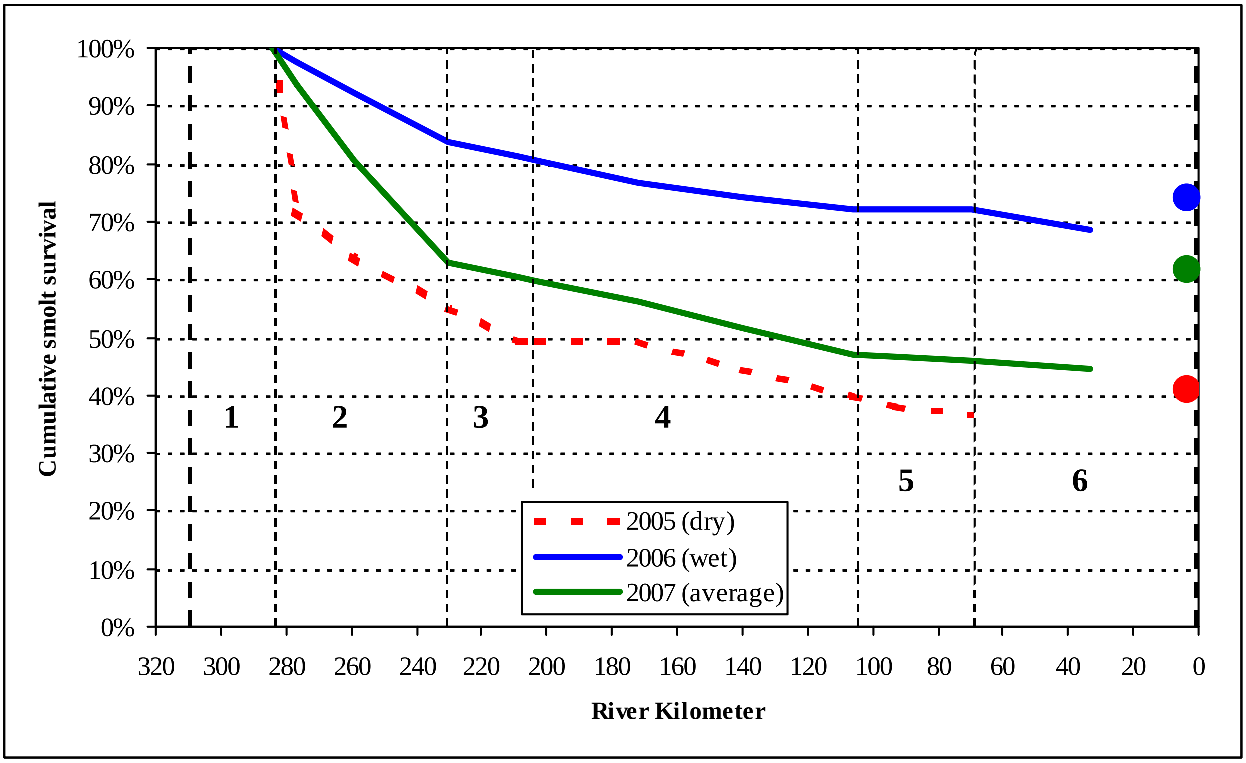


*Figure 10. Longitudinal survival patterns of smolts radio-tracked after passing down the Klamath River near the Shasta River confluence versus the full out-migration survival rates the CFS (2007) lifecycle model predicted for Shasta River coho under 2005 (red), 2006 (blue), and 2007 (green) flow conditions. Estimated cumulative annual survivals of radio-tracked smolts are shown as lines, while predictions based on the CFS model are given as large colored dots.*

Given the problem posed by the flow-survival scalar within the existing Klamath coho model, it occurred to me that it would be appropriate to step back a bit and think about exactly what is being modeled here and how it might be better modeled. The model requires, at a minimum, an annual estimate of each coho population’s smolt survival rate. The available evidence suggests that this rate is influenced by the ecology of fish diseases in the Klamath River, river temperatures, and smolt behavior.  Each of these things is related to flow.  In concept, influential factors may be affecting smolt survival rates at two temporal scales.  Inter-annual differences in flow may define coarse-scale variations in ecological conditions within the river, and flow variations within a given spring (March-May) period will affect the thermal experience, disease exposure, and migratory behavior of individual coho smolts.  Modeling the survival consequences for smolts of the coarse-scale variation in ecological conditions along the river may well be easier and make more sense at present than does trying to get at finer-scale variations in fish survival without first having more resolute empirical data for use in developing model functions that operate on short time-steps.  It may ultimately turn out that the coarser-scale influences of flow on smolt emigration survival are substantially dominant at the scale of individual coho populations in the Klamath system, particularly if such influences include the annual virulence of pathogens (e.g., *C. shasta*) or if smolt migration timing and behavior vary enough among years to enhance fish survival in a variable environment.  Regardless of what is ultimately determined through further research, having a flow-survival function within the model that operated reasonably well on an annual time-step, at least as an option in the near term, could be important.  It would make what I view as an otherwise unreliable model informative or helpful to people until such time as the details of finer-scale smolt survival are better understood.

With this in mind, I conducted an analysis of the available smolt survival data, one paralleling the analysis of Cramer Fish Sciences (CFS 2007), but that was (1) not dependent on adjustment to some hypothetical survival baseline, (2) based on mean spring (March-May) flows within river reaches and (3) focused on developing reach-specific survival functions for annual smolt survival while making a minimum number of assumptions about the forms of relationships between flow and survival.  Using simple linear regression, I found what appear to be clear relationships between mean spring flow and survival rates for smolts released into the Klamath River near the Shasta confluence as they passed through reach MS2 (bounded by the Shasta and Scott rivers) and through a section of the river composed of reaches MS3 and MS4 (bounded by the Scott and Salmon rivers).  These relationships, depicted graphically in Figure 11, are based on only three annual smolt survival data points for each section of river, but they represent all of the information that is available at present.  Smolt survival rates seen in the Klamath below the Salmon River confluence were not as easily parsed into a satisfactory flow-based function, and seemed to me most likely to yield survival predictions reasonably close to those seen in each year if a simple 3-year average of the observed survival rates was adopted as reflective of fish survival conditions there until further research is conducted.  The average smolt survival rate I calculated for the mainstem Klamath below the Salmon River was 0.872 survival/100km (SE=0.043).

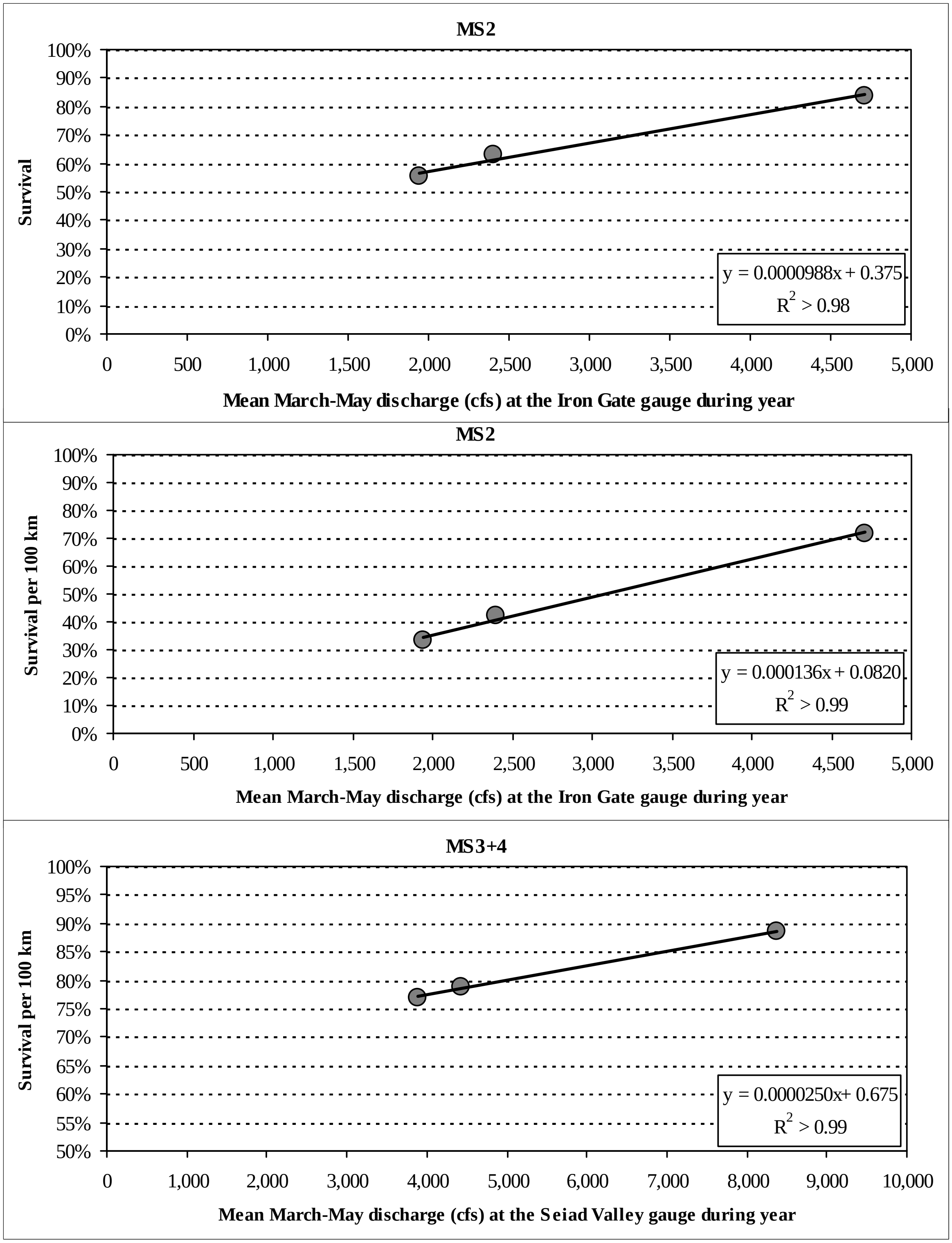


***Figure 11. Preliminary relationships between the magnitude of spring flows and the survival of coho smolts emigrating through two specific sections of the Klamath River: reaches MS2 (Shasta River to Scott River; top and middle panels) and MS3+4 (Scott River to Salmon River; bottom panel).***

Given the reasonably good fits I found to available data, one logical near-term alternative to the approach the November 2007 model uses to simulate smolt survival in the mainstem Klamath would be to model specific survival scenarios that were consistent with explicit hypotheses about how flow-related ecological conditions in the river during spring affect patterns and rates of smolt emigration survival on an annual basis. Under this approach, survival functions would be driven by mean annual March-May flow and used to predict the annual smolt survival for coho entering the mainstem Klamath from specific parts of the system. Multiple plausible hypotheses appear consistent with the available data and my analyses. Three (there are likely others) are described below, and could be applied in the model using survival functions identified in Table 4.

- **Scenario A.** Smolt survival through reach MS1 is exceptionally high, but survival downstream is driven by ecological conditions related to seasonal flows. Smolt survival to the Scott River is similar for all fish passing through reach MS1 or entering the mainstem from the Shasta River. Smolts initiating their seaward migration through the mainstem Klamath at points downstream of the Shasta River experience the same mortality rates as do Shasta fish when migrating through common segments of the river.

- **Scenario B.** Smolt survival in mainstem reaches MS1 and MS2 is strongly driven by ecological conditions encountered within the river close to the point of entry (or the point of origin for any fish that over-wintered in the mainstem). These conditions are related to seasonal discharge and are particularly poor in years when spring flows are severely low. Survival to the Scott River is similar for all fish entering reaches MS1 and MS2. Smolts initiating their seaward migration through the mainstem Klamath at points downstream of the Scott River experience the same mortality rates as do Shasta River fish when migrating through common segments of the mainstem Klamath.

- **Scenario C.** Survival in mainstem reaches MS1, MS2, and MS3 is strongly driven by ecological conditions encountered in the main river close to the point of entry. These conditions are related to seasonal discharge and are particularly poor in years when spring flows are severely low. Survival to Portuguese Creek is similar for all fish entering reaches MS1, MS2, and MS3. Smolts initiating their seaward migration through the mainstem Klamath at points downstream of Portuguese Creek experience the same mortality rates as do Shasta River fish when migrating through common segments of the mainstem Klamath.

***Table 4. Integrated functions intended to represent specific, flow-driven survival scenarios for the seaward migration of coho smolts down the mainstem Klamath River below Iron Gate Dam. Each scenario is based on available data and specific hypotheses about the broad, annual consequences of interactions between spring flows, meteorology, water temperatures, pathogen ecology, salmonid behavior, and smolt mortality. The annual rate of smolt survival to the ocean for a specific population or sub-population of coho would be the product of that population or sub-population.***

| **Reach of smolt entry or origin** | **Survival scenario** | | |
|---|---|---|---|
| | **Scenario A** | **Scenario B** | **Scenario C** |
| MS1 | 1.00 | 1.00 | 1.00 |
| MS2 | $S = (0.000136igdq+0.082)^{D/100}$ | $S = 0.0000988igdq+0.375$ | 1.00 |
| MS3 | $S = (0.0000250sdvq+0.675)^{D/100}$ | $S = (0.0000250sdvq+0.675)^{D/100}$ | $S = (0.0000988igdq+0.375)*$<br>$(0.0000250sdvq+0.675)^{0.265}$ |
| MS4 | $S = (0.0000250sdvq+0.675)^{D/100}$ | $S = (0.0000250sdvq+0.675)^{D/100}$ | $S = (0.0000250sdvq+0.675)^{D/100}$ |
| MS5 | $S = 0.872^{D/100}$ | $S = 0.872^{D/100}$ | $S = 0.872^{D/100}$ |
| MS6 | $S = 0.872^{D/100}$ | $S = 0.872^{D/100}$ | $S = 0.872^{D/100}$ |

*S* - Survival assumed for smolts passing through the reach on their way toward the ocean, structured so that their cumulative survival to the ocean matches that for the disease/survival scenario or hypothesis.
*D* – Distance (km) traveled within reach.
*igdq* – The mean March-May discharge (in cfs) for the year modeled, as measured at the USGS gauge site below Iron Gate Dam, CA.
*sdvq* – The mean March-May discharge (in cfs) for the year modeled, as measured at the USGS gauge site at Seiad Valley, CA.

Though the functional relationships given for the survival scenarios outlined above are consistent with available data, it must be noted *again* that all of the data on smolt survival along lower reaches of the Klamath are based on fish originating in areas close to Iron Gate Dam. While populations in these "upper" areas seem to be those most likely to be affected by BOR water management, it is not at all clear that the survival or mortality patterns of their smolts when in the lower reaches of the river is the same as that of smolts originating in lower portions of the basin. There may well be delayed disease-related mortality affecting the longitudinal pattern here. At present, there is little information on this issue, and the hypothesis that smolt survival in the lower river reaches is similar whether fish originate up near Iron Gate Dam or farther down in the system is probably reasonable but certainly worth testing in future telemetry studies.

In order to test the performance of the spring flow-survival scalars proposed here if incorporated into the Klamath coho model. I used the scalars to estimate annual smolt survivals from the mouth of the Shasta River to the ocean for each of the years already used to test the interacting scalars in the November 2007 model, and added two additional years to the tests of both sets of scalars: 2001 (another "dry" one), and 2004 (another "average" one). Results of this test are summarized in Table 5. *The new flow-survival scalars focus on annual spring flows as a coarse-scale driver of smolt survival through the interaction of flow, meteorology, water temperature, disease, and fish behavior. They do not, at least at present, appear to require the use of other interacting scalars in order to perform far better than the functions applied to biweekly cohorts of smolts in the latest model from CFS.*

***Table 5. Comparison of empirical and model-based survival estimates for coho smolts migrating down the mainstem Klamath River from two source areas below Iron Gate Dam to the river's mouth.***

| Smolt origin | Source of survival estimate | Estimated smolt survival from Klamath River entry to the estuary | | | | |
|---|---|---|---|---|---|---|
| | | 2001 (dry) | 2004 (average) | 2005 (dry) | 2006 (wet) | 2007 (average) |
| Iron Gate Hatchery | telemetry studies | --- | --- | <37%[a] | <68%[b] | <45%[b] |
| | original lifecycle model | 30% | 45% | 28% | 77% | 60% |
| | Scenario A | 30% | 35% | 35% | 62% | 40% |
| Shasta River | telemetry studies | --- | --- | <37%[a] | <68%[b] | <45%[b] |
| | original lifecycle model | 35% | 51% | 41% | 75% | 61% |
| | Scenario A | 30% | 35% | 35% | 62% | 40% |

[a] A Cramer Fish Sciences analysis of data from Stetzer et al (2006) suggests that the survival of radio-tagged smolts from Iron Gate Hatchery and the Shasta River to the Trinity confluence, 69 km above the Klamath River's mouth, was 37%. Adjusted for smolt survival seen between that confluence and the mouth in other years of study, this estimate would likely be closer to 34%.

[b] Beeman (2007) estimated survival from Iron Gate Hatchery and the Shasta River to a point 33 km about the river's mouth as 68%. If adjusted to the river's mouth on the basis of the survival rate observed during this year in the lower-most section of the river studied, this estimate would likely be closer to 65%.

[c] Preliminary analyses by John Beeman (USGS, Willard, Washington, pers comm.) suggest survival from Iron Gate Hatchery and the Shasta River to a point 33km above the river's mouth as 45%. If adjusted to the river's mouth on the basis of the survival rate observed during this year in the lower-most section of the river studied, this estimate would likely be closer to 43%.

One additional issue related to the flow-survival scalars and the consequences of salmonid diseases in the mainstem Klamath River has not been explicitly addressed, and I am not sure how it should be addressed other than to make clear it needs to be recognized and either accounted for in future modeling or discussed in whatever final report CFS prepares describing their model. Specifically, there is good reason to think that some as yet undefined level of delayed, disease-related mortality affecting radio-tagged coho smolts involved in studies of emigration survival has not been quantified because it occurs after these fish have passed the final tag detection site on the lower Klamath. To the degree that this is occurring, existing study-based estimates of smolt emigration survival may be biased high. This is a disturbing thought given that it appears the survival of yearling smolts from the Shasta River downstream to the Klamath River estuary, particularly during low water years, may be as bad as is seen in the mainstem Columbia River where such fish must pass eight hydroelectric dams and reservoirs containing significant populations of predatory fish.

### *Coho life-cycle model revisions based on my hypothesis-driven smolt survival relationships*

Per your suggestion, I have managed to develop a rough, beta-version of the CFS model that adds the hypothesis-driven functions for annual smolt survival outlined in this section of my memo to changes outlined earlier and made accessible to CFS at my firm's website (http://www.canby.com/cwbio/html/reports.html). The beta-version might also be something to share with CFS staff or others at some point, provided it was recognized in advance that there has been insufficient time for error-checking or to examine whether the modifications create new model misbehaviors. My sense is that this beta-version might provide a good platform for making the Klamath coho model something that the biologists involved in the BOR's coho modeling process will use and improve in the future.

## FINDINGS REPORTED IN THE DRAFT MODEL REPORT (CFS 2007; pages 65-102)

Prior to sorting out the exact basis for how the CFS coho model was handling smolt emigration survival, or whether the model's relevant functions could be improved, I had developed a set of graphical summaries depicting model outputs on equilibrium smolt and adult abundances for each coho population present upstream of the Trinity River confluence under a variety of ocean survival and river flow conditions. These summaries were informative, and several showed patterns that were not consistent with suggestions by CFS (2007) that populations in the basin below Iron Gate Dam would be resilient to an extended period of "worst-case" conditions. In fact, the model outputs suggested that some populations below the dam are vulnerable if one considers their small size and inconsistent performance. I could provide these summaries, but now that it is clear to me they were based on a model that functioned poorly, presenting them in this memo would strike me as less than helpful.

### *Effects of flow at Iron Gate Dam on stream temperature*

CFS (2007; page 65) states that the reservoir above Iron Gate Dam tends to release waters that during late spring and early summer "are below equilibrium temperature on the order of 2-4$^{o}$C from the dam down to the Scott River". The authors should provide a citation for this statement, or provide data and model results that help clarify the pattern of this effect. It would also be helpful if Cramer Fish Sciences could clarify how flow management above Iron Gate Dam interacts with flow management at the dam to affect temperatures, since the two may not be entirely the same thing.

The suggestion that BOR water management has a limited effect on smolt survival (CFS 2007; page 65) is not as clear as it might be to readers of the report. The revised Model Report should probably draw a clearer connection between model results and this suggestion, at least to the degree that such a connection can be drawn. My sense from working with the CFS model is that this may or may not be what the model shows if one looks carefully at the performance of individual coho populations in the areas nearest Iron Gate Dam.

### *Population performance*

The discussion of population performance in the draft Model Report (CFS 2007; pages 72-84) places limited focus on the size and performance of individual coho populations in the areas closest to Iron Gate Dam and focuses more strongly on the performance of the Klamath basin's full aggregate of coho populations. This approach, particularly given that the model has only been run for a short sequence of simulation years, is strongly influenced by the abundance levels at which the model is initiated and by the relative sizes of the populations dispersed across the entire basin. A more informative analysis would focus on individual populations, and provide a clear indication of the status and performance of those populations closest to Iron Gate Dam because it would make sense that these are the ones most likely to be affected by the management actions being modeled.

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