San Joaquin River Group

- Modesto Irrigation District
- Turlock Irrigation District
- South San Joaquin Irrigation District
- San Joaquin River Exchange Contractors

P.O. Box 4060
Modesto, CA 95352
(209)526-7405
(209)526-7315-Fax

- Merced Irrigation District
- Oakdale Irrigation District
- Friant Water Users Authority
- City and County of San Francisco

April 13, 2006

William Loudermilk
California Department of Fish & Game
San Joaquin Valley – Southern Sierra Region 4
1234 E. Shaw Avenue
Fresno, CA 93710

Re: SJRGA Review of "San Joaquin River Fall Run Chinook Salmon Population Model"

Dear Bill:

Enclosed is the SJRGA's review of the California Department of Fish and Game's "San Joaquin River Fall Run Chinook Salmon Population Model." The review points out significant flaws in the model. In our opinion the model should not be used for any discussion of flow, population or policies because of these serious deficiencies.

We are forwarding a copy of this review to the SWRCB and the technical and management committee of the San Joaquin River Agreement.

Sincerely,

Allen Short
Coordinator

Encl.

C: SJRA Management & Technical Committee

S.P. Cramer & Associates, Inc.
600 NW Fariss Rd
Gresham, OR 97030
(503) 491-9577, FAX (503) 465-1940
www.spcramer.com

TECHNICAL MEMORANDUM

TO: Tim O'Laughlin
FROM: Brian Pyper, Steve Cramer, and Michele Simpson
DATE: March 20, 2006
SUBJECT: Review of the California Department of Fish and Game's "San Joaquin River Fall-run Chinook Salmon Population Model."

This is an initial review of the California Department of Fish and Game's (CDFG) proposed model for evaluating and recommending adjustments to the Vernalis flow objectives ("San Joaquin River Fall-run Chinook Salmon Population Model"). We have examined CDFG's model and associated report in some detail, and outline several concerns and recommendations below. The subject of evaluating the effects of flow on production of fall-run Chinook is complicated and plagued with uncertainty, and CDFG has undertaken an ambitious first step toward addressing these problems. Unfortunately, we conclude that CDFG's current model is not appropriate for evaluating the impacts of alternative VAMP flows, and therefore does not provide a sufficient basis for changing the current Vernalis flow regime.

Before we summarize our key concerns, it is important to clearly define two terms used by CDFG, which we also adopt in this review. First, escapement refers to the number of parental spawners observed in a given year. In contrast, cohort production refers to the number of adult offspring produced by a given annual escapement[1]. Note that CDFG did not account for harvests when computing cohort production, and hence all estimates of cohort production are based only on escapement counts across years.

CDFG's model and analyses are considered insufficient for the following reasons:

- The mathematical formulation of the model results in a highly questionable relationship between flow and cohort production. This relationship is not consistent with available data.
- As a result, the model is a poor predictor of cohort production. The poor performance of the model is not immediately obvious because the model currently compares predicted and observed values of annual escapement rather than cohort

[1] The adult offspring of a given annual escapement typically return to spawn 2 to 4 years later. Thus, to compute cohort production, estimates of the age structure of returning adults are required. For example, if the 2008 escapement produces 1,000 adults that return in 2010 (age-2 fish) and 1,000 adults in 2011 (age-3 fish), then the cohort production for 2008 will be 2,000.

production. Cohort production should be used as the primary measure for evaluating model performance.

- Because the relationship between flow and adult production is not reasonable, the current version of the model should not be used to evaluate the possible effects of alternative VAMP flows on adult production.
- The statistical methods used to derive two key relationships in the model are overly simplistic and unconventional. These two relationships determine (1) the number of smolts that migrate to Mossdale, and (2) the survival rate of smolts between Mossdale and Chipp's Island.
- The relationship determining smolt production (i.e., the number of smolts at Mossdale) appears highly unrealistic because (1) it does not adequately account for the role of parental spawners, and (2) it assumes that smolt production is determined almost exclusively by spring flow.
- The relationship determining smolt survival is assumed to be a linear function of flow. However, it appears to be equally plausible that the relationship is nonlinear. This survival relationship is critical to the evaluation of alternative VAMP flows and a more rigorous statistical analysis should be conducted.
- The model does not include a density-dependent function even though there is clear evidence of density dependence in the data. This omission is highly unconventional and contributes to the unrealistic nature of the smolt-production relationship.
- The only environmental variable affecting salmon production that is included in the model is Vernalis spring flow. As a result, the effects of spring flow are likely overstated. Other potentially important determinants of juvenile growth and survival are not included. In particular, the potential beneficial effects on fry of high flows during January to March should be considered.
- The model does not account for harvests when computing estimates of cohort production or annual escapement. Given that large fluctuations in harvest rates occurred over the time period used in the model, comparisons between observed and predicted values of cohort production (or worse, between observed and predicted annual escapement) that do not account for harvests are likely to be poor indicators of model performance.

Overview

CDFG's report begins by examining relationships between San Joaquin River (SJR) fall-run Chinook abundance/survival and four variables: exports, harvests, escapement (evidence of density dependence), and spring Vernalis flow. Their report suggests that all relationships except those for flow are weak; and hence, only flow is retained as a component of the model. Furthermore, the argument is made that flows during spring are the key determinant of salmon production because correlations between spring flows at Vernalis and salmon production are strong. Specifically, the report states (page 17):

> When Vernalis spring flow magnitude and duration ratio is regressed against smolt production at Mossdale, a statistically significant relationship results

> (Figure 29). This suggests that the combination of spring Vernalis flow magnitude, and duration, strongly influence salmon production in the SJR [San Joaquin River]. If the length of the smolt protection window (e.g., number of days) is regressed with average flow against smolt out-migration abundance, a strong correlation results (Table 3). As reported above, the SJR flow at Vernalis is strongly correlated with SJR Water Year Type Index, and SJR salmon cohort abundance is strongly correlated with spring Vernalis flow magnitude and duration. Thus it is not a surprise that there is a strong correlation between SJR cohort abundance and SJR Water Year Type Index (Figure 30). These findings support the statements regarding the linkage between spring Vernalis flow magnitude, duration, and frequency and SJR salmon escapement abundance, in the Department's comments to the SWRCB in March 2005.
>
> These findings that spring Vernalis flow magnitude, duration, and frequency are strongly associated with SJR salmon abundance, in combination with the lack of substantial cause and effect relationships between either Delta exports, ocean harvest, and/or density dependence related to spawner abundance, indicate that is it appropriate to develop a conceptual SJR salmon population prediction model that includes spring Vernalis flow magnitude, duration, and frequency, and excludes ocean harvest, Delta exports, and in-river spawner abundance (e.g., referencing density dependent mortality).

This passage summarizes well the scientific arguments and conclusions used by CDFG to justify the structure of their population model. A key relationship motivating the exclusive focus on spring flow is the correlation between Vernalis spring flow and SJR cohort production from 1967 to 1999 (Figure 1). The CDFG model attempts to account for this apparent linkage between spring flow and adult production using several life-stage specific linear relationships. Model predictions of adult escapement were then calibrated to, and compared with, historic escapement estimates (Figure 2). At first glance, the close correspondence between observed and predicted escapements suggests that the model has successfully depicted the key determinants of adult production and could be used as a tool for evaluating the potential benefits of alternative Vernalis flow objectives. However, we have several serious concerns regarding both the mathematical formulation and biological basis of the model, as identified in detail in the following sections.

Concerns and Recommendations

1. Mathematical formulation results in a highly questionable effect of flow

The model formulation results in a relationship between flow and salmon production that is not supported by the data. This was likely not the intention of the analyst, but rather the result of combining two stages in the model that both include effects of flow. A brief summary of the model is required to demonstrate this problem.

The model is basically comprised of three linear relationships that relate escapement (spawner abundance) and springtime Vernalis flow to future adult production. The specific relationships are as follows:

(1) Mossdale Smolts = B1 * Escapement + B2 * Vernalis Flow

(2) Mossdale-to-Chipp's Smolt Survival = B3 * Vernalis Flow

(3) SJR Escaping Adults = B4 * Smolts surviving to Chipp's Island

= B4 * (Mossdale Smolts * Mossdale-to-Chipp's Survival).

The baseline coefficients (B1 through B4) were initially determined from linear regressions of available data and then adjusted in a calibration phase. In equation (1), Vernalis Flow is the average over the period March 15 through June 15, while equation (2) uses daily flows over this period to compute the survival of each daily fraction of smolts passing Mossdale (these fractions differ depending on water year type). Two versions of equation (2) are available, corresponding to HORB-in and HORB-out. In equation (3), a fixed age structure is used to partition returning spawners (SJR Escaping Adults) across several years.

As discussed below, in the current model the contribution of spawners (Escapement) to smolt production is negligible in comparison to the contribution due to flow. That is, the value of B1 in equation (1) is effectively zero. If we further assume that daily flows are roughly constant over the period March 15 through June 15, then equations (1) to (3) can be reduced to a single equation:

(4) SJR Escaping Adults = B4 * (Mossdale Smolts * Mossdale-to-Chipp's Survival)

= B4 * (B2 * Vernalis Flow) * (B3 * Vernalis Flow)

= B5 * (Vernalis Flow)^2,

where B5 = B2 * B3 * B4.

Thus, the underlying population dynamics of the model can be described by a single equation in which adult cohort production is directly proportional to the square of spring flow:

$$\text{Adult Cohort Production} \propto (\text{Spring Flow})^2$$

This "quadratic" relationship implies that adults are produced at an ever increasing rate as spring flow increases. The questionable nature of this relationship is not immediately apparent in the model because CDFG uses annual escapement as the primary measure for assessing the performance of model predictions. However, predictions of cohort

production (i.e., the total number of spawning adults produced by a given annual out-migration of juveniles) are the truly important measure because it is cohort production that is determined by the model relationships. Annual escapements are simply a byproduct of cohort production, whereby cohort production is partitioned across several years of escapement using estimates of age structure.

We therefore plotted the predictions of cohort production as a function of spring flow (using the "calibrated parameters" provided in the model upon opening the file). The results are shown in Figure 3. Clearly, the model predictions of cohort production are extremely low in years of low spring flow, and do not approach the regression line of the historic data (see Figure 1) until roughly 15,000 cfs. Predictions increase rapidly thereafter, reaching 147,000 adults for the 1982 cohort (Figure 3). However, the observed (historic) cohort production for 1982 was only 91,000.

In other words, an explicit comparison of observed versus predicted cohort production (rather than observed versus predicted annual escapement) would reveal that the model is a poor predictor of cohort production. The apparent consistency between observed and predicted annual escapements identified by CDFG in Figure 2 is very misleading – this comparison is not a good measure of model performance because it obscures the underlying relationship between observed and predicted cohort production.

Although the flow-production relationship defined in equation (4) was surely not the intention of the model, such a formulation has dramatic implications for assessing the benefits of VAMP flows. Specifically, the model can be expected to exaggerate the benefits of large flow increases in wet years, while at the same time underestimating the benefits of modest flow increases in dry years — *and it will do so regardless of what parameters are used because the quadratic behavior is built into the model structure.* In terms of escapement, the model would be expected to predict trivial incremental benefits of increased flow when at or below 7,000 cfs, for example, but large if not extraordinary benefits for high-flow conditions (e.g., 15,000 cfs or greater) (see Figure 3). In other words, the model would predict a flow increase of 100 cfs would be far more beneficial if the starting flow were 15,000 cfs than if the starting flow were 100 cfs, which is precisely the opposite of what we would intuitively expect. Thus, given the formulation problem outlined above, we conclude that the current model is not appropriate for evaluating the impacts of alternative VAMP flows.

It is often the case that a simple model is preferable to a more complex one, especially when data are limited. However, at the same time, it is critical to understand why higher spring flows are associated with higher cohort production. In the absence of a clear mechanistic relationship, or even a plausible guess, the exercise of translating an empirical correlation into reasonable management recommendations is highly speculative and suspect. For example, there is no obvious reason to expect that increasing flow for a single week would affect smolt survival in that week in the same way that the season-wide average flow is related to season-wide smolt survival. However, that is exactly what the above model formulation assumes. In any case, the relationship between spring flow and adult production implied by equation (4) cannot be supported by available data, nor

is it consistent with research in salmon population dynamics. Any reformulation of the model should carefully consider the underlying mechanistic basis and form of the implied relationship between flow and adult production. In addition, the validity of model predictions should be assessed primarily in terms of cohort production rather than annual escapement.

2. Statistical methods used to derive relationships are too simplistic

Linear regressions were used to derive the relationships for Mossdale smolt production (equation 1), Mossdale-to-Chipp's survival rate (equation 2), and SJR Escaping Adults (equation 3). In all cases, the Y-intercepts of these regressions were set to zero when used in the model. However, the following problems arise with one or more of the relationships as a result of the statistical approach:

(1) The data violate the assumption of normality and should be transformed.
(2) The method used is not a conventional approach to analyzing such data and likely results in a misleading and biased relationship.
(3) The relationship is driven by a few data points that have high "leverage." This results in highly significant relationships that appear convincing or well defined when in fact they should be treated with greater uncertainty and skepticism.
(4) The relationship does not appear to be linear.
(5) An influential data point is arbitrarily excluded from the analysis.

These issues are addressed in greater detail in the following sections.

3. Relationship determining Mossdale smolt production appears unrealistic

The first key relationship in the model predicts smolt abundance at Mossdale as a function of both spawner abundance and Vernalis spring flow (equation 1 above). This equation was initially derived via linear regression using data from 1988 to 2004. These data and the regression results are shown here in Table 1. The regression model had the following form:

(5) Mossdale Smolts = X1 * Escapement + X2 * Flow + Y-intercept

where X1 and X2 are coefficients. Note that the 1989 data point was excluded when computing the regression. The regression has a very high R-squared value (0.89), which suggests that 89% of the variability in smolt production can be explained by flow and escapement. However, flow is highly significant ($P < 0.001$) whereas escapement is not ($P = 0.20$). The authors note that when only flow is considered in the model, the R-square remains high (0.88), indicating that most of the variability in smolt production could be attributed to changes in flow. They conclude that "Spring Vernalis flow has a powerful influence upon smolt production in the SJR" (page 18 of CDFG 2005). In the spreadsheet model, the Y-intercept was set to zero and the escapement and flow coefficients were changed slightly in the calibration phase to X1 = 15 and X2 = 149. In

addition, it appears that the Mossdale smolt estimates used by CDFG may have included unmarked hatchery smolts, which likely biases the estimated relationships to some extent.

Effects of spawners

There would seem to be several serious problems with this relationship. First, escapement in the model has very little influence on smolt production. The coefficients used in the model correspond to roughly 15 smolts per spawner and 150 smolts per cfs of flow. Thus, a single cfs of spring flow produces 10 times as many smolts at Mossdale than does a single spawner. Consequently, omitting spawners from the model by setting the escapement coefficient to zero has almost no effect on the results. That is, the model produces numerous smolts even when there are no parental spawners. This is highly irregular from a modeling perspective, and from a biological perspective it is, of course, impossible.

Note that the estimated number of smolts produced per spawner each year ranged from 21 to 817 (Table 1), with median and average values across years of 82 and 194, respectively. While flow conditions undoubtedly contributed to this variation, the first step in the modeling process should be to establish a reasonable relationship between parental spawners and juvenile production. Clearly, the model value of 15 smolts per spawner is not reasonable.

Vernalis spring flow

The second problem is that all of the benefits of flow accrue during the migration period from March 15 through June 15. Thus, there are at least three implicit hypotheses underlying the smolt-production relationship:

(1) several million pre-smolts are produced each year regardless of spawner abundance;
(2) environmental conditions (including flow) prior to migration do not appreciably affect the survival or production of pre-smolts; and thus,
(3) spring flow in the San Joaquin River (and relevant tributaries) is the single key determinant of the survival rate, and hence abundance, of smolts that migrate to Mossdale.

To our knowledge, there is no solid empirical evidence to support any of these hypotheses. A larger role must certainly be placed on spawner abundance; otherwise, adult abundance goals for future escapement would seem largely irrelevant. Moreover, because the model relates Mossdale smolt production to the average daily flow from March 15 through June 15, the flow pattern over this spring period is also of little consequence in the model. For example, the same predicted smolt production can result from either a scenario where steady, moderate flows occur over the whole period, or a scenario where generally low flows occur through May followed by a strong peak in early June. Given that relatively few smolts pass Mossdale during June, the first scenario would be expected to provide much more suitable conditions for survival.

Omitted data point

A third potential problem is that CDFG omitted the 1989 data from the regression analysis because that year was an outlier (see Figure 4). They state (page 18):

> "… [the 1989] Mossdale smolt estimate was not consistent with other years. Why the 1989 smolt estimate is high relative to other years is currently unknown."

However, outliers can often provide valuable insight, and it is generally recommended that outliers not be discarded unless there is good reason to believe that the data are unreliable. Instead, the effects of outliers on the analysis should be thoroughly examined. In this case, the data point may indeed provide valuable insight. The Mossdale smolt estimate was roughly 4.2 million even though Vernalis flow was only 1,900 cfs, yet the preceding escapement estimate was comparatively high at 20,583 (Table 1). Thus, a reasonable explanation for the large smolt estimate is that it resulted from a large escapement. The fact that CDFG excludes this smolt estimate because it is inconsistent with the expected relationship with flow suggests a strong preconceived bias toward a largely unsupported hypothesis (i.e., that spring flow is the only important determinant of smolt production).

Statistical approach

Finally, from a statistical perspective, the regression analysis and results used to derive the smolt-production relationship are highly questionable. First, the form of the linear function is not a conventional approach. Typically, the effects of escapement and flow would be examined using stock-recruitment models (Quinn and Deriso 1999). We revisit this topic in more detail below when discussing evidence of density dependence.

Second, standard diagnostics of the regression (i.e., statistical methods for assessing the validity of model assumptions and the influence of individual data points) reveal that the relationship is primarily determined by two data points (1995 and 1998). This occurs because flows in these years were much greater than in other years (Figure 4). Although such contrast in the data is essential to reliably estimate flow effects, it must be recognized that these two years have an enormous influence on the results. In statistical terms, these data points have high "leverage". For example, if these two years are omitted (along with 1989), the estimated effect of flow becomes much weaker (55 smolts per cfs) and is no longer statistically significant ($P = 0.17$) (see dashed line in Figure 4). Moreover, the variability explained by the model is reduced from 88% to just 14% (i.e. R-square value * 100%). If these data points are omitted but 1989 is included, then flow accounts for virtually none of the variation (R-square = 0.0) and the estimated effect of flow becomes negative (a reduction of 22 smolts per cfs).

The point of these comparisons is to illustrate that the regression analysis is highly sensitive to a few data points. The 1995 and 1998 data drive the relationship and result in overly confident estimates of the flow effect. Thus, the estimated smolt-production relationship should be viewed with considerable caution. This conclusion is reinforced by the fact that the Mossdale smolt estimates are themselves highly uncertain (see Table 4 of CDFG 2005). Finally, the possible presence of marked and unmarked hatchery

smolts in the Mossdale smolt estimates should be accounted for, otherwise, relationships are likely to be biased.

Summary

To summarize, the relationship governing Mossdale smolt production appears unrealistic. It was derived using a questionable statistical approach, and is almost exclusively a function of spring flow whereby each additional 1,000 cfs produces 150,000 smolts. In contrast, escapement has a very limited role in which 1,000 spawners produces just 15,000 smolts. Furthermore, no other factors during spawning, egg-incubation, or fry rearing are considered as important determinants of smolt production. We further address these limitations in the following sections.

4. Clear evidence of density dependence is omitted from the model

Several data sets and exploratory analyses are discussed in the report that leads to the conclusion that there is little evidence of density dependence. Unfortunately, the rational provided makes little sense. In fact, most of the evidence is consistent with the anticipated effects of density dependence. In brief, a lack of density-dependent mortality implies that juvenile or adult production will be roughly proportional to escapement across the range of observed escapement levels. That is, if escapement doubles, so will juvenile or adult production. Thus, the number of juveniles or adults produced per spawner will appear to roughly constant regardless of spawner abundance. In contrast, the existence of density-dependent mortality (e.g., direct or indirect mortality due to competition among spawners or juveniles within confined habitats) will result in a declining rate of juvenile or adult production as escapement increases. Consequently, production will increase as escapement increases from low levels, but will gradually level off or perhaps even decline as escapements reach higher levels where competition intensifies.

Stock-recruitment curves, which depict particular forms of density-dependent relationships, are usually an integral part of any salmon population dynamics model (Quinn and Deriso 1999). To demonstrate that the SJR data exhibit clear evidence of density dependence, we fit stock-recruitment curves to three data sets provided in CDFG (2005). In the report, two of these data sets were cited as providing little evidence of any relationship between escapement and adult production (density dependent or not), but strong evidence that flow primarily determined adult production. These conclusions were again based on linear regressions of the form described above for Mossdale smolt estimates (equation 5).

Mossdale smolt data

First, we examined the Mossdale smolt data (Table 1). As noted in Comment #3 above, a more conventional approach to estimating the effects of escapement and flow on smolt production is to develop a statistical model based on a stock-recruitment curve. For example, the following formulation is based on the Ricker curve (Ricker 1975; Quinn and Deriso 1999):

(6) Mossdale Smolts = Escapement * exp(a – b * Escapement + c * Flow),

where "a" is a parameter denoting the number of smolts produced per spawner at low spawner abundance (i.e., where there is little density dependence), "b" determines the level of density dependence, and "c" denotes the effect of flow on smolt production. Note that flow was standardized to have a mean of zero so that "a" can be correctly interpreted as mean smolts per spawner. Based on strong theoretical, statistical, and empirical grounds (Quinn and Deriso 1999), it is usually appropriate to transform the data using natural logarithms so that equation (6) becomes:

(7) ln(Mossdale Smolts/Escapement) = a – b * Escapement + c * Flow.

Evidence of density dependence can be assessed visually by plotting values of ln(Mossdale Smolts/Escapement) versus Escapement, as shown in Figure 5. The data clearly suggest that the number of smolts produced per spawner declines as escapement increases (i.e., there is apparent evidence of density dependence). A lack of density dependence would be indicated by a flat relationship (no apparent decline). In addition, note that value for 1989 no longer appears to be an extreme outlier (compare Figure 4 and Figure 5).

When equation (7) is fit to the data, the resulting parameter estimates indicate strong evidence of density dependence (P = 0.001), but only weak evidence of an effect of flow on smolt production (P = 0.17). Furthermore, from a biological perspective, the Ricker relationship provides a more reasonable interpretation of the data than does the approach used by CDFG. For example, at a flow of 5,000 cfs, each spawner is estimated to produce roughly 270 smolts when the escapement is 1,000 spawners, but only 50 smolts per spawner at an escapement of 20,000. The flow parameter suggests that smolt production increases by roughly 5% per 1,000 cfs increase in flow. Finally, the statistical properties of the Ricker relationship appear far more robust than the regression approach of CDFG (e.g., lower leverage for individual data points, much closer approximation to normal distribution, etc.).

Our analysis is not meant to be definitive. The Ricker model has a specific form of density-dependent relationship that may not be appropriate for SJR fall Chinook salmon. In fact, our exploratory analysis suggests that the Beverton-Holt curve would provide a better description of the smolt data set. In addition, it is well known that stock-recruitment analyses can produce biased and imprecise results when applied to short data sets that contain considerable measurement error (Quinn and Dersio 1999). Nevertheless, a modeling approach that is based on a stock-recruitment curve should provide a much more reasonable and defensible smolt-production relationship than is currently used in the CDFG model.

<u>Escapement versus cohort production</u>
Similarly, our results for the escapement versus cohort production data provided in CDFG (2005) further demonstrate that (1) there is strong evidence of density dependence in adult production data for SJR Chinook salmon, and (2) an analytical approach based

on a stock-recruitment curve provides a more reasonable and defensible interpretation of the data than the approach used by CDFG. The two data sets analyzed by CDFG were comprised of (1) female spawners, cohort production, and spring flow for the Tuolumne River (1973-1999, Table 1 of CDFG 2005) and (2) total SJR production (1981-1999, Table 2 of CDFG 2005). In both cases, density dependence was evident in plots of cohort production per spawner as a function of female spawners.

To test for effects of both escapement and flow on cohort production of adults, we fit Ricker relationships of the form shown in equation (7), but using ln(flow) rather than flow as an independent variable (the former provided better fits to the data). For both data sets, the effects of density dependence and flow were significant ($P < 0.02$). Further, the interpretation of the coefficients differed markedly from those of the CDFG approach. For example, for the Tuolumne data, CDFG estimated that only 0.40 adults were produced per female spawner (regardless of spawner abundance); while spring flow generated 3.2 adults per cfs of flow. Again, this implies that escapement has a trivial contribution to cohort production in comparison to flow, which is not biologically reasonable. In contrast, the Ricker relationship indicated that for average flow conditions, each female spawner produced an average of 2.5 adults at low escapement (e.g., 500 fish), but only 1 adult at an escapement of 5,000 females. Thus, the Ricker fit provides a more biologically reasonable relationship between escapement and cohort production than the 0.40 adults per female spawner estimated by CDFG's regression approach.

The neglect of stock size has serious management implications. The only way smolt production could fail to be directly proportional to parent stock size is if there were severe habitat constraints between escapement and smolt outmigration, such that the relevant habitat was fully saturated even in years of poor escapement. But this would imply a severe form of density dependence, which CDFG does not consider. The assumption that parent stock size has little effect on production explicitly contradicts statements regarding the absence of habitat limitations, and raises fundamental questions about the point of trying to increase cohort production in the first place.

In summary, there is strong evidence of density dependence in SJR production data. Further, the use of stock-recruitment analysis to estimate the relative contributions of escapement and flow to juvenile or adult production should provide more reliable and defensible results than those obtained by CDFG. We therefore strongly recommend that CDFG investigate alternative stock-recruitment relationships, and incorporate an appropriate form into their model as a basis for relating escapement to juvenile production.

5. Relationship for smolt survival appears too simplistic

The second key relationship in the model predicts smolt survival between Mossdale and Chipp's Island as a function of Vernalis spring flow (equation 2 above). To derive this relationship, CDFG used linear regressions with survival-rate data for CWT releases collected from VAMP reports. Regressions were computed separately for CWT releases conducted with or without the HORB in place (HORB-in and HORB-out). The flow-

survival relationships used in the "calibrated" model are shown in Figure 6. Predicted survival rates for HORB-in are roughly 1.6 times greater than for HORB-out. As discussed in the report, exports were not considered to be an important determinant of survival rate in comparison to flow.

Shape of the flow-survival relationship

Our greatest concern with these relationships is that a linear form may not be appropriate. Accurate estimation of the benefits of VAMP flows depends critically on the shape of the flow-survival relationship. Thus, careful consideration should be given to the plausible form of relationship and the consequences of uncertainty in the relationship.

In general, researchers have found it difficult to establish strong relationships between flow conditions and the survival of migrating juvenile salmon. In cases where such relationships are apparent, the shape is typically nonlinear rather than linear. Specifically, survival estimates tend to increase rapidly as flow increases from low levels, but then survival rates remain relatively constant across a range of moderate to high flow conditions (Smith et al. 2003; Pyper and Smith 2005). For example, Newman (2003) estimated such a relationship for CWT releases of Chinook salmon in the Sacramento River.

Statistical approach

We contend that the approach used by CDFG is overly simplistic, and as a result, little consideration is given to alternative forms of the flow-survival relationship. Specifically, using linear regression and forcing the Y-intercept to equal zero can easily result in a biased depiction of the flow-survival relationship. Admittedly, it is difficult to obtain reliable statistical descriptions of these relationships because data are limited and highly variable. It appears that CDFG used just seven data points to estimate the HORB-out regression and nine data points for the HORB-in regression (see Figure 34 in CDFG 2005).

A more conventional approach to analyzing smolt survival data is to use regression analysis based upon the logistic model described above or some related form of generalized linear model (McCullagh and Nelder 1989; Newman and Rice 2002; Newman 2003; Pyper and Smith 2005). To illustrate the importance of considering alternative flow-survival relationships, we fit logistic regression models to survival-rate data found in VAMP (2004, 2005). These data are for 38 CWT experimental groups released between 1989 and 2005 at Dos Reis, Mossdale, and Durham Ferry (Table 2). Survival-rate estimates were derived using differential recovery rates (DRR or CDRR) computed using paired releases at Jersey Point and CWT recoveries at Chipp's Island and Antioch (see VAMP 2005 for details).

In the logistic regression analysis, we examined two forms for the flow-survival relationship by using Vernalis flow as a variable in one case, and the natural logarithm of flow or "ln(flow)" in the other case. We also included indicator variables to test for differences among release sites (Dos Reis versus Mossdale and Durham) and HORB placement (in versus out).

We found that both forms of the flow-survival relationship were statistically significant ($P < 0.01$), and each form accounted for similar proportion of the variability in survival rate. In other words, both forms appear equally viable from a statistical perspective. Note, however, that the two forms imply quite different relationships between flow and survival (Figure 7). The form that used "flow" as a variable suggests that survivals slowly increase from roughly 6% on average for low flows (e.g., 1,000 cfs) to about 30% for high flows (Figure 7A). In contrast, the "ln(flow)" form suggests that survival rates increase more rapidly as flows increase from low levels (Figure 7B). This latter relationship is generally consistent with the findings of other research (Newman 2003; Smith et al. 2003; Pyper and Smith 2005). Incidentally, the coefficient for HORB suggested that survival rates are 1.3 times greater when the HORB is in place, though the difference was not significant ($P = 0.1$). Likewise, survival rates for releases at Dos Reis were estimated to be 10% greater than at Mossdale and Durham Ferry, but again, the difference was not significant ($P = 0.3$).

These results suggest that alternative flow-survival relationships may be more appropriate than the simple linear forms used by CDFG (Figure 6). For the data we examined, it would not be appropriate to force a linear model through the origin. The "ln(flow)" form intersects the origin (Figure 7B), but this relationship suggests that the benefits of increasing VAMP flows will be greater at low flows (e.g., between 1,000 and 5,000 cfs) than at higher flows. In contrast, the CDFG relationship suggests that the benefits of increasing VAMP will be constant regardless of the initial flow level. Our concern that a linear form may not be appropriate is further supported by the analysis discussed in the next section.

Finally, it is abundantly clear from the data we analyzed that much of the variability in survival rates appears to be related to annual conditions other than flow. In some years survival rates appear high despite low flows, while in other years survival rates are low when flow conditions are high, such as in 2005 (VAMP 2005). This indicates that other factors might be just as or even more important than flow. Careful review of other environmental conditions associated with the individual smolt survival estimates may indicate other factors that affect smolt survival. For example, incorporating other variables such as temperature and exports (e.g., Newman 2003) could help to refine estimates of the underlying flow-survival relationship.

Summary

In summary, because the flow-survival relationship is critical to the assessment of alternative VAMP flows, we strongly recommend that CDFG conduct a more comprehensive analysis of CWT experimental releases and the implications of alternative flow relationships. Approaches such as those used by Newman and Rice (2002) and Newman (2003) would provide more reliable and defensible results. In addition, a careful review of whether individual smolt survival experiments met paired release assumptions (Burnham et al. 1987) would potentially reduce the number of useable data points, but would improve the confidence in the use of these data. As one means of improving the statistical power of any relationship between smolt survival and flow,

survival rate estimates based on other recovery locations such as ocean harvest should be considered.

As a final example, we refer to Figure 40 of CDFG (2005), which considers tributary smolt-survival study results for hatchery releases. For all three tributaries, it appears that a non-linear flow-survival relationship is indeed appropriate. Although a linear relationship is shown for Merced, this relationship implies that data collected at higher-than-observed flows would lead to a non-linear form (i.e., survival cannot continue to increase linearly because it already approaches 100% at 4000 cfs). In addition, the survival estimates in Figure 40 appear to be limited to Mossdale recoveries to the exclusion of several other recovery sources (export salvage, trawls, harvest, and escapement) that should be included. It is not clear if (1) the Stanislaus and Merced studies have been reviewed with regard to meeting study assumptions and adjusting evaluation flows as has been done for Tuolumne survival evaluations and (2) if the estimates of Tuolumne survival are only those resulting from the review process.

6. Model relationships are not consistent with a key subset of data

To recap, the CDFG model uses two key relationships that link Vernalis spring flows to Mossdale smolt production (equation 1) and subsequent smolt survival through the Delta (equation 2). For the final step in the life cycle, CDFG computed the number of SJR escaping adults (cohort production) as a function of smolts at Chipp's Island (equation 3).

To derive this final relationship, CDFG applied their smolt-survival function to the Mossdale smolt estimates (Table 1, with 1989 excluded) in order to estimate the number of smolts surviving to Chipp's Island. CDFG then estimated a linear regression between these Chipp's smolt estimates and the known (observed) cohort production for those years (see Figure 36 of CDFG 2005). This relationship is shown here in Figure 8 (solid line). Again, in the model the Y-intercept was set to zero and a "calibrated" coefficient of 0.05 was used (i.e., B4 = 0.05 in equation 3). This value of 0.05 simply indicates that a constant survival rate of 5% was assumed across all years for the survival of Chipp's smolts to adult cohort production. We refer to this value as the assumed "marine" survival for Chipp's smolts. This model relationship is also shown in Figure 8 (dashed line).

This final step by CDFG poses several problems, and the data involved illustrate a major shortcoming of the model. First, the linear regression used by CDFG was again driven by two data points with very high leverage (1995 and 1998; Figure 8). Thus, the relationship and the corresponding moderate R-square value should be interpreted with caution. Further, setting the Y-intercept to zero appears to be highly inappropriate for the data in Figure 8. By doing so, the implied relationship underestimates cohort production for virtually all years in which the Chipp's smolt estimate is less than 200,000 (Figure 8, dashed line). Instead, the data in Figure 8 strongly suggest that a nonlinear relationship may exist between the Chipp's smolts and cohort production (or alternatively, that estimates of Chipp's smolts are largely unreliable). We examined two apparent inconsistencies that should be carefully considered in further model developments.

Implied marine survival

In terms of checking model consistency, a useful question to ask is: "how consistent are the data in Figure 8 with the assumed value for marine survival of 5%?" To address this question, we computed the implied marine survival for each year as follows:

Marine survival = 100% *(Observed cohort production)/(Chipp's smolt estimate).

These values are shown in Figure 9. It is important to recognize that these values of implied marine survival are derived from the CDFG model predictions of Chipp's smolt abundance. Therefore, the degree to which these implied marine survivals differ from the value assumed in the model (e.g., 5%) is an indication of model consistency. As shown in Figure 9, there is strong lack of consistency between the implied estimates of marine survival and the assumed value (5%). The implied values range from 1% to 63%, with a median or average value across years of 28%. In fact, the implied marine survival is greater than 20% in nine of the 14 years. It is also clear that implied marine survival tended to be much greater on average for years in which Vernalis spring flow was low (e.g., < 5,000 cfs).

This lack of consistency arises because a linear model with Y-intercept = 0 does not provide a reasonable fit to the data in Figure 8. The approach taken by CDFG easily obscures this lack of consistency as well as the high variability in implied marine survival rates (Figure 9). A more conventional approach would be to explicitly examine and model values of implied marine survival, which would better expose the high uncertainty and potential nonlinear form of the relationship.

Mossdale smolt-to-adult survival as a function of Vernalis flow

More generally, however, a closer inspection of the Mossdale smolt data (Table 1) reveals a more profound inconsistency between model predictions and the observed data. Specifically, we asked: "what is the relationship between Mossdale smolt-to-adult survival as a function of Vernalis spring flow, and how does it compare with the implied model relationship?" Because these smolt data and cohort production data were used by CDFG to develop both the Mossdale smolt production relationship (equation 1) and the final Chipp's smolt-to-adult relationship (equation 3), they provide an essential check of consistency for the flow-survival relationship for Mossdale smolts (equation 2).

We computed the smolt-to-adult survival of Mossdale smolts for each migration year as follows:

Smolt survival = (Observed cohort production)/(Mossdale smolt estimate).

We then plotted smolt-to-adult survival as a function of Vernalis spring flow, and added the CDFG model predictions to the plot (Figure 10).

There are two important features of Figure 10. First, it is obvious that the model predictions of smolt-to-adult survival tend to grossly underestimate the observed values.

This is a reflection of the key point raised in Comment #1 – the model provides unreasonably low predictions of cohort production when spring flows are less than 15,000 cfs. It also reflects the inconsistency just noted, in which implied marine survival was shown to be generally much higher than the value of 5% assumed by the model.

The second important feature is that the observed smolt and adult data, which provide a critical foundation for CDFG's model development, do not support the simple linear flow-survival relationship used in the model to predict Mossdale smolt survival (equation 2). Recall that this latter equation was based on survival-rate data from CWT releases. In Comment #5, we suggested that the CWT data provide evidence of a nonlinear relationship between spring flow and smolt survival. This is clearly evident again in the Mossdale smolt data (Figure 10).

In summary, we recommend that CDFG thoroughly examine the consistency between observed data and model predictions for each of the key life-stage components of their model. Modeling and examining relationships in terms of survival rates will help to avoid the pitfalls encountered in the current analysis.

7. Importance of April/May flow is likely overstated

As noted above, the model assumes that adult cohort production is almost entirely a function of spring flow, largely because spring flow is thought to determine the number of smolts arriving at Mossdale. However, it seems highly unlikely that spring flow is as important as the CDFG report and model imply. The strong correlation between spring flow and cohort production is certainly suggestive, but this correlation should not be interpreted as proof of a causal mechanism. It is well known that correlations between measures of fish productivity and environmental variables are often misleading and regularly breakdown as new data are collected (Walters and Collie 1988; Myers 1998). Furthermore, spring flows are likely to be highly correlated with flow conditions during other periods, as well as with other variables (e.g., temperature) that might be important determinants of juvenile growth or survival. Such "collinearity" limits the potential to distinguish between important and unimportant variables (e.g., Smith et al. 2003).

The CDFG report notes that flow conditions during the spring correlate strongly with water-year type. To the extent that SJR fall-run Chinook benefit from high flow conditions during several life stages, spring flow could easily appear more important than it is. In the Stanislaus River, for example, the number of juveniles that outmigrate as fry during Januaryto March can greatly exceed the production of smolts (Demko et al. 2000). Further, although large numbers of fry emigrate from the spawning area above Oakdale (RM 40) every year, fry migrants are only observed reaching Caswell (RM 9) in the lower river in years of high flow in January to March (Demko et al. 2000). As a result, the greatest differences in abundance of outmigrants from the Stanislaus River between low and high flow years is not in the abundance of smolts in April-May, but in the number of fry emigrating in January-March (Figure 11). Presumably, high flows during these months would also benefit pre-smolts, while high flows in the San Joaquin River during January to March would presumably enhance fry survival as well. There is

currently compelling evidence that fry arriving in the lower San Joaquin River and Delta during January- to March might contribute to cohort production, particularly in wet years, as evidenced by correlation and regression analyses.

Correlation Analysis

We conducted two sets of exploratory analyses to demonstrate that the apparent strong effects of spring flow are potentially confounded by effects of flow during other life stages. First, we examined how average flows each month of the year were correlated to fall-run escapement data for the Tuolomne River (flow gage at Modesto), Merced River (flow gage at Stevinson), and Stanislaus River (flow gage at Modesto). The escapement and flow data extended from 1952 to 2003. Assuming that adult recruits were predominantly age-3 fish, escapement data were lagged such that flow conditions would correspond to the first year of life. Correlations were computed for 15 months extending from October to the following December, thereby covering periods of adult migration, spawning, egg incubation, juvenile rearing and migration, and early ocean residence.

We also examined how monthly flows were correlated to each other. Because CDFG used April-May average flows in their model, we determined the correlation of April-May flows to the averages for each month of the year. If adult production is largely determined by April-May flows, then we would expect to see similar patterns of correlations between (1) escapement and monthly flows, and (2) between April-May flows and monthly flows.

For all three rivers, correlations between monthly flows and escapement varied little across months (Figure 12 and Figure 13). Although correlations were generally higher between February and late summer, the highest correlation of escapement was not always to flow in April and May. In contrast, the pattern of how flows were correlated to each other was not equivalent across months. April-May flows were uncorrelated to flows the preceding October to December, and had increasing correlations with flows in months temporally closer to April and May (as expected) (Figure 12 and Figure 13).

The different correlation patterns for escapement and April-May flows suggest that adult production is not primarily determined by April-May flows. Given that April-May flows are only well correlated with temporally proximal months, then escapement should only be well correlated with flows in months proximal to April-May. In contradiction to this deduction, escapement is well correlated to flows across most of the year. Thus, the correlation of escapement to April-May flows appears to reflect a correlation to the flow year magnitude than it does the flow specifically in April-May. Of course, it is not possible through simple correlations to determine when or where other factors might also influence production, or if flow is even the variable involved. It appears likely that wet years provide a series of cumulative and beneficial effects that enhance survival rates. On the other hand, it is also unclear to what extent measurement errors in escapement estimates and variation in adult age structure may obscure correlations with monthly flows.

Regression Analysis

This second set of analyses provides more concrete evidence that February and March flows may indeed be an important determinant of cohort production. Specifically, we examined relationships between SJR cohort production and Vernalis flows during April/May and February/March (Table 3). The cohort production data, which were obtained from Table 2 of the CDFG report, extend from brood years 1981 to 1999. To examine the potential effects of flow on cohort production, we fit linear regressions of ln(cohort production) versus ln(flow). Natural logarithms of these variables were used to better normalize the data.

As expected, regression results were similar for both April/May and February/March flow. In either case, the effect of flow was highly significant ($P < 0.001$). In fact, February/March flow provided a slightly better fit to cohort production (R-square = 0.74 for February/March flow and 0.69 for April/May flow). Of course, this result does not imply that February/March flow is the key determinant of cohort production. Rather, it demonstrates the difficulty of identifying important variables when those variables are highly correlated. In this case, the correlation between April/May flow and February/March flow is 0.84.

Nevertheless, there were some notable differences across years in April/May and February/March flow that may relate to cohort production. In particular, there were four brood years (1983, 1996, 1998, and 1999) for which average April/May flows at Vernalis were less than 6,000 cfs while February/March flows were 9,000 cfs or more (Table 3). The ratio of February/March to April/May flows in these years ranged from 1.6 to 4.9 (Table 3). Furthermore, the cohort production in these years was roughly 60% greater on average than the predicted values based on April/May flow. To test for possible effects of February/March flow in addition to April/May flow, we added the natural logarithm of the February/March to April/May flow ratio to the regression. The effect of the flow ratio was statistically significant ($P = 0.041$) and indicated an important contribution of February/March flow to cohort production. For example, predictions of cohort production increased by 70% when February/March flow was double that of April/May flow, and decreased by 43% when February/March flow was half that of April/May flow.

Once again, these analyses are only exploratory and more investigation is required to confirm or dismiss the possibility that February/March flow is an important determinant of cohort production. However, from a biological perspective, if high flows in April and May are hypothesized to be highly favorable for smolt survival, then it also seems reasonable that flow conditions in January to March would be of considerable importance to both migrating fry and juveniles rearing in tributaries and the San Joaquin River/Delta.

8. Lack of accounting for harvest distorts variation in cohort production

As noted above, a key relationship motivating CDFG's exclusive focus on spring flow is the correlation between Vernalis spring flow and SJR cohort production (Figure 1). However, CDFG ignored harvests when calculating cohort production and used only

escapement counts across years. Thus, the CDFG time series of cohort production is only a rough indicator of the number of adult Chinook produced by each year's escapement.

The number of adults produced is usually referred to as recruitment, and it is the sum of spawners plus the fish captured in fisheries. In the case of SJR fall Chinook, the majority of adults were likely captured each year in ocean fisheries, while only a minority survived to spawn. There were major changes in ocean harvest regulations in recent years that caused a dramatic decrease in the fraction of recruits that were harvested. This fraction is estimated by the Central Valley Index (CVI), which is calculated each year by the Pacific Fishery Management Council as a metric for tracking their management of ocean harvest. Other estimates of the fraction of San Joaquin fish harvested can be estimated through analysis of CWT recoveries from fall Chinook produced at Merced Hatchery, but the CVI serves as a reasonable surrogate to make our point. Over the course of the data set used by CDFG in the SJR Chinook model, the CVI indicates that the fraction of adult recruits that escaped the ocean fishery fluctuated from a low near 20% (CVI =80%) to a high near 70% (CVI = 30%) (Figure 14). This is more than a three-fold difference, and demonstrates why escapement counts do not provide a consistent index of adult recruitment (i.e., "actual"cohort production) over the time period used by CDFG in their model.

In order to accurately estimate relationships between environmental variables and cohort production (or survival to adulthood), the latter should be measured in terms of total recruitment rather than an as index based on spawner escapement. Similarly, in order for model predictions to be meaningful, they should incorporate variability in harvests over time. However, in their report, CDFG dismisses the role of harvests. They state (page 15):

> It has also long been postulated that ocean harvest is a controlling influence upon long-term in-river salmon escapement population trends in the SJR. However, comparing the Central Valley Harvest Index [CVI] to Sacramento and San Joaquin River salmon escapements (Figures 25) suggests that ocean harvest is not a variable influencing the long-term trend in SJR salmon escapement. Unlike in the Sacramento River basin, no noticeable increase in SJR salmon escapement occurred when substantial changes in ocean sport and commercial fish regulations restricted ocean harvest in recent years. Additionally, regressing the Central Valley Harvest Index against annual SJR escapement produces a weak, but statistically significant, regression correlation (Figure 26). The relationships depicted in Figure 25 and 26 suggest that factors other than ocean harvest, such as in-Delta or in-river conditions, are controlling the long-term SJR salmon escapement trend.

Unfortunately, this is not a compelling argument. The influence of harvests should not be treated as a hypothesis. For example, it is obviously the case that every SJR fish caught in the ocean harvest is a fish that cannot return to spawn. Thus, changes in ocean harvest unequivocally change subsequent escapement. While it is true that SJR escapements did not increase proportionately in recent years when ocean harvest decreased considerably,

this simply suggests that escapements would have been considerably lower than actually observed had harvests remained high. Indices such as the CVI may be uncertain, yet they reflect available data regarding harvests, which are an actual and important component of cohort production. Given the apparent fluctuations in harvest rates over time (Figure 14), comparisons between observed and predicted values of cohort production (or worse, annual escapement) that do not account for harvests are likely poor indicators of model performance.

Acknowledgments

We thank Peter Baker, Tim Ford, Noah Hume, and Ron Yoshiyama for contributing helpful comments on an earlier draft of this memorandum.

References

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture. American Fisheries Society Monograph 5. Bethesda, Maryland.

CDFG [California Department of Fish and Game]. 2005. San Joaquin River fall-run Chinook salmon population model. Final Draft.

Demko, D.B., C. Gemperle, S.P. Cramer, and A. Phillips. 2000. Outmigrant Trapping of Juvenile Salmonids in the Lower Stanislaus River Caswell State Park Site 1999. Prepared by S.P. Cramer and Associates, Inc. for U.S. Fish and Wildlife Service, Stockton, CA.

McCullagh, P. and Nelder, J.A. 1989. Generalized Linear Models (second edition), Chapman and Hall, London.

Myers, R.A. 1998. When do environment-recruitment correlations work? Reviews in Fish Biology and Fisheries. 8: 285-305.

Newman, K. and J. Rice. 2002. Modeling the survival of Chinook salmon smolts outmigrating through the lower Sacramento River system. Journal of the American Statistical Association, 97: 983-993.

Newman, K. 2003. Modeling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon. Statistical Modeling, 3: 157-177.

Pyper, B.J. and D.L. Smith. 2005. Evaluation of salmonid survival resulting from flow alterations to the lower Yakima River. Prepared by S.P. Cramer and Associates, Inc. for Kennewick Irrigation District and United States Bureau of Reclamation, Yakima, WA.

Quinn, T.J.II, and R.B. Deriso. 1999. Quantitative fish dynamics. Oxford Univ. Press. New York, NY.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. No. 191, pp.1-382.

Smith, S.G., Muir, W.D., Hockersmith E.E. et al. 2003. Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon. North American Journal of Fisheries Management. 23: 939-961.

VAMP. 2004. Vernalis Adaptive Management Plan 2004 Annual Technical Report.

VAMP. 2005. Vernalis Adaptive Management Plan 2005 Annual Technical Report.

Walters, C. J., and J. C. Collie. 1988. Is research on environmental factors useful to fisheries management? Journal of the Fisheries Research Board of Canada 45:1848-1854.

Table 1. San Joaquin River escapement and Vernalis spring flow versus Mossdale smolt abundance. Data and regression results taken from "SJR Model_Supporting Files.xls" (note that errors are contained in Table 4 of CDFG (2005)).

Year	SJR Prior Year Escapement (Spawners)	3/15-6/15 Mean Daily Vernalis Flow (cfs)	Mossdale Smolt Estimate	Smolts per Spawner	Adult Cohort Production
1988	25,169	1,983	1,188,584	47	344
1989	20,583	1,900	4,241,862	206	765
1990	3,212	1,362	263,932	82	1,098
1991	658	1,237	537,397	817	3,267
1992	590	1,101	280,395	475	3,677
1993	1,373	3,213	269,035	196	4,221
1994	2,826	1,840	453,245	160	6,722
1995	5,126	20,719	3,361,384	656	27,594
1996	4,368	8,497	1,155,319	264	7,164
1997	8,962	4,759	635,517	71	18,221
1998	16,394	18,776	2,844,637	174	48,491
1999	16,088	5,762	438,979	27	18,471
2000	17,347	5,441	484,703	28	21,608
2001	39,447	2,853	848,488	22	13,763
2002	26,659	2,382	733,839	28	NA
2003	25,625	2,467	550,446	21	NA
2004	15,109	2,575	333,080	22	NA

Multiple Regression (excludes 1989)

Equation: Smolts = X1 * Escapement + X2 * Flow + Y-intercept

R-squared = 0.89

	Estimate	Lower 95%	Upper 95%	P-value
Y-intercept	7847	-312339	328033	0.96
X1 (Escapement)	9.7	-5.8	25.2	0.20
X2 (Flow)	143.9	113.7	174.1	<0.001

Table 2. Survival rate data for CWT releases of fall Chinook salmon in the San Joaquin River. Data were obtained from VAMP (2004, 2005). Survival-rate estimates are for differential recovery rates (DRR or CDRR) computed using paired releases at Jersey Point and CWT recoveries at Chipp's Island and Antioch (see VAMP 2005 for details). For HORB, 1 = HORB-in and 0 = HORB-out.

Year	Day	Release Site	Survival Estimate	Vernalis Flow (cfs)	HORB
1989	20-Apr	Dos Reis	0.160	1,970	0
1990	16-Apr	Dos Reis	0.060	1,210	0
1990	2-May	Dos Reis	0.030	1,440	0
1991	15-Apr	Dos Reis	0.090	809	0
1994	15-Apr	Mossdale	0.000	1,387	0
1994	1-May	Mossdale	0.133	2,468	1
1995	17-Apr	Dos Reis	0.310	18,735	0
1996	1-May	Dos Reis	0.135	6,279	0
1996	1-May	Dos Reis	0.060	6,279	0
1997	29-Apr	Dos Reis	0.288	5,454	1
1997	29-Apr	Dos Reis	0.180	5,454	1
1997	8-May	Dos Reis	0.281	5,057	1
1998	16-Apr	Mossdale	0.305	24,825	0
1998	17-Apr	Dos Reis	0.313	24,868	0
1998	24-Apr	Dos Reis	0.280	20,005	0
1999	29-Apr	Mossdale	0.400	7,061	0
1999	29-Apr	Dos Reis	0.651	7,061	0
2000	19-Apr	Durham	0.242	6,635	1
2000	21-Apr	Mossdale	0.329	6,251	1
2000	28-Apr	Durham	0.156	5,670	1
2001	30-Apr	Durham	0.211	4,358	1
2001	1-May	Mossdale	0.159	4,430	1
2001	7-May	Durham	0.193	4,418	1
2001	8-May	Mossdale	0.201	4,464	1
2002	18-Apr	Durham	0.154	3,142	1
2002	19-Apr	Mossdale	0.194	3,200	1
2002	25-Apr	Durham	0.130	3,308	1
2002	26-Apr	Mossdale	0.094	3,408	1
2003	21-Apr	Durham	0.023	3,499	1
2003	22-Apr	Mossdale	0.035	3,416	1
2003	28-Apr	Durham	0.000	3,328	1
2003	29-Apr	Mossdale	0.007	3,418	1
2004	23-Apr	Mossdale	0.026	3,172	1
2004	24-Apr	Durham	0.026	3,149	1
2005	2-May	Durham	0.069	7,726	0
2005	3-May	Dos Reis	0.050	7,804	0
2005	9-May	Durham	0.051	8,498	0
2005	10-May	Dos Reis	0.070	8,727	0

Table 3. San Joaquin River cohort production and daily average Vernalis flow for April/May and February/March. Cohort production data from Table 2 of CDFG (2005).

Year of Spawning	Female Spawners (Escapement)	Cohort Production	April/May Vernalis Flow (cfs)	Feb/March Vernalis Flow (cfs)	Ratio of Feb/March to April/May Flow
1981	7,486	58,798	20,809	8,353	0.40
1982	8,784	91,991	34,109	35,820	1.05
1983	2,313	22,052	3,762	9,167	2.44
1984	20,264	6,055	2,299	2,989	1.30
1985	38,125	42,824	14,177	16,890	1.19
1986	10,719	2,513	2,522	2,775	1.10
1987	2,707	344	1,963	1,815	0.92
1988	11,705	765	1,929	1,629	0.84
1989	1,758	1,098	1,294	1,563	1.21
1990	227	3,267	1,109	1,268	1.14
1991	282	3,677	1,155	1,780	1.54
1992	528	4,221	3,488	2,862	0.82
1993	1,068	6,722	1,916	2,113	1.10
1994	2,078	27,594	20,943	10,473	0.50
1995	1,804	7,164	7,784	12,587	1.62
1996	2,316	18,221	4,662	22,701	4.87
1997	9,135	48,491	19,837	23,712	1.20
1998	6,173	18,471	5,932	9,638	1.62
1999	6,285	21,608	5,165	9,855	1.91

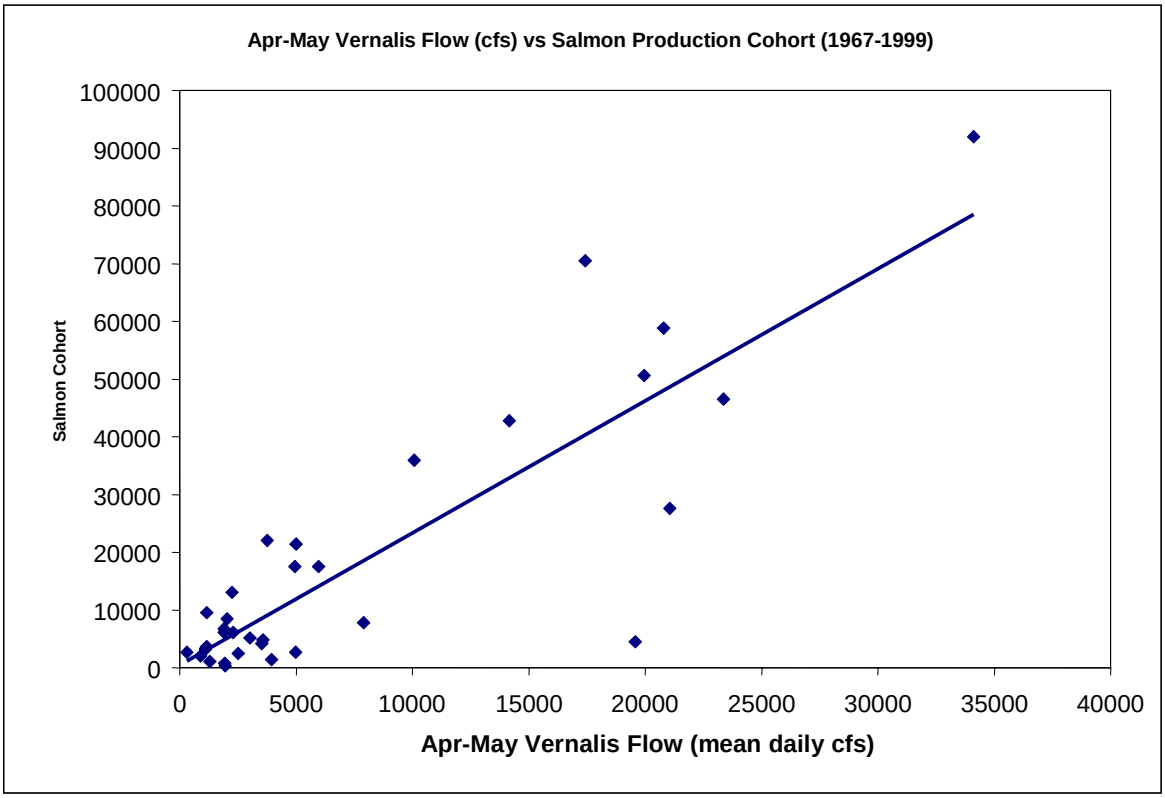


Figure 1. Cohort production of San Joaquin River fall Chinook as a function of Vernalis spring flow. This figure corresponds to Figure 3 of CDFG (2005). Cohort production is the sum of adult spawning escapements attributed to an annual cohort of juveniles.

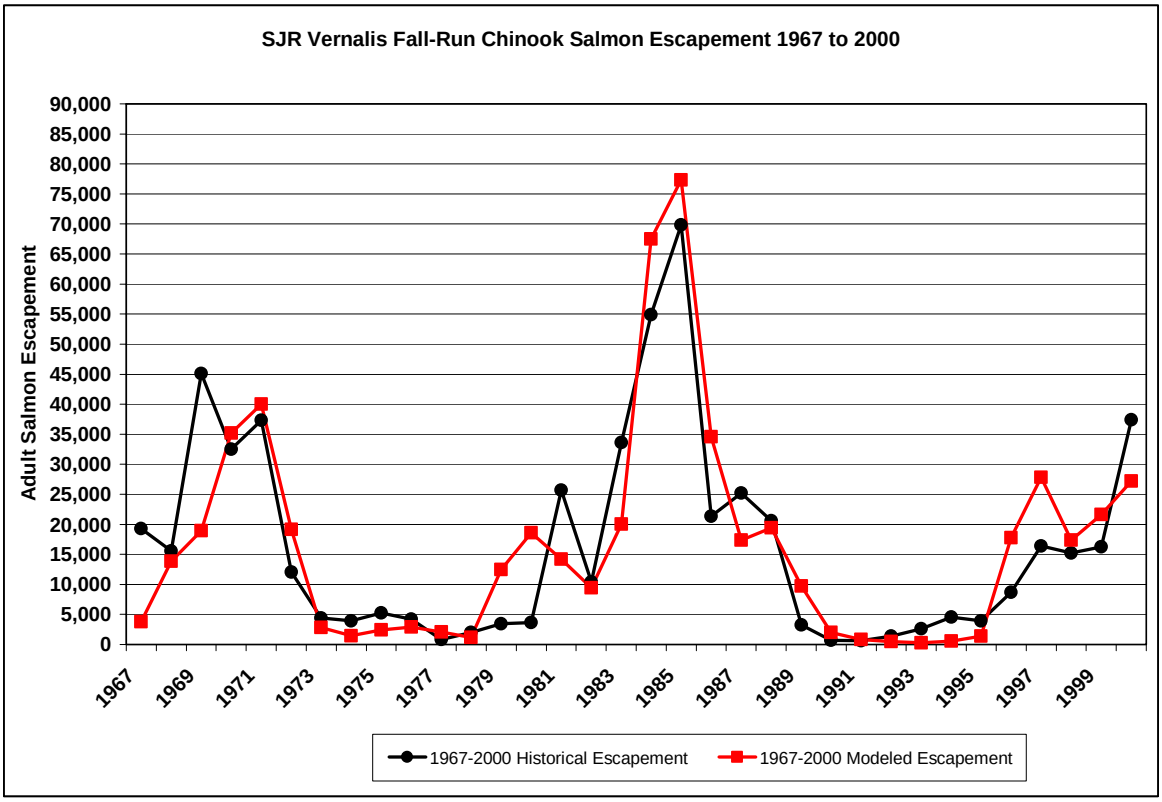


Figure 2. Observed and predicted adult escapement of SJR fall Chinook salmon. Predicted (modeled) escapements are for the "calibrated" version of the model. This figure corresponds to Figure 41 of CDFG (2005).

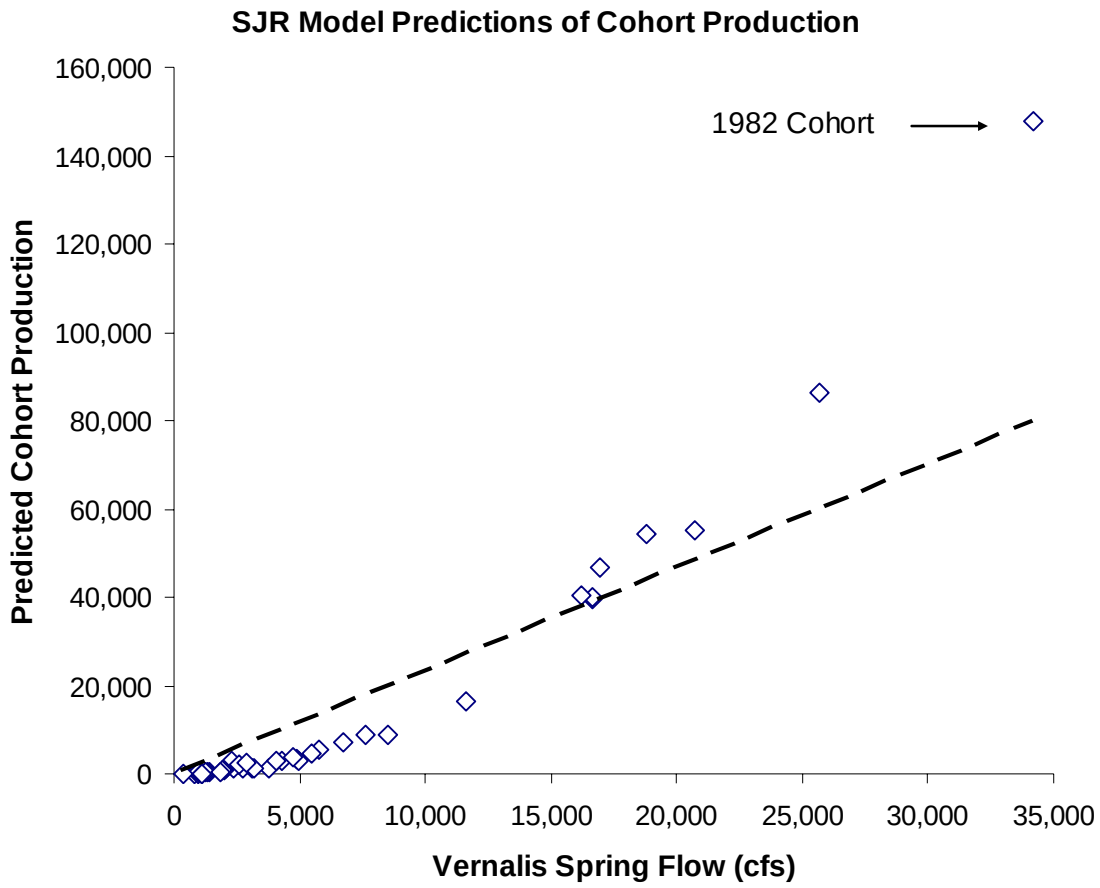


Figure 3**.** Model predictions of SJR cohort production as a function of Vernalis spring flow (1967 to 1999). The dashed line corresponds to the regression line for the historic cohort production data shown in Figure 1. Model predictions seriously underestimate cohort production for flows less than 10,000 cfs, while at very high flows, the model overestimates production as shown for the 1982 cohort.

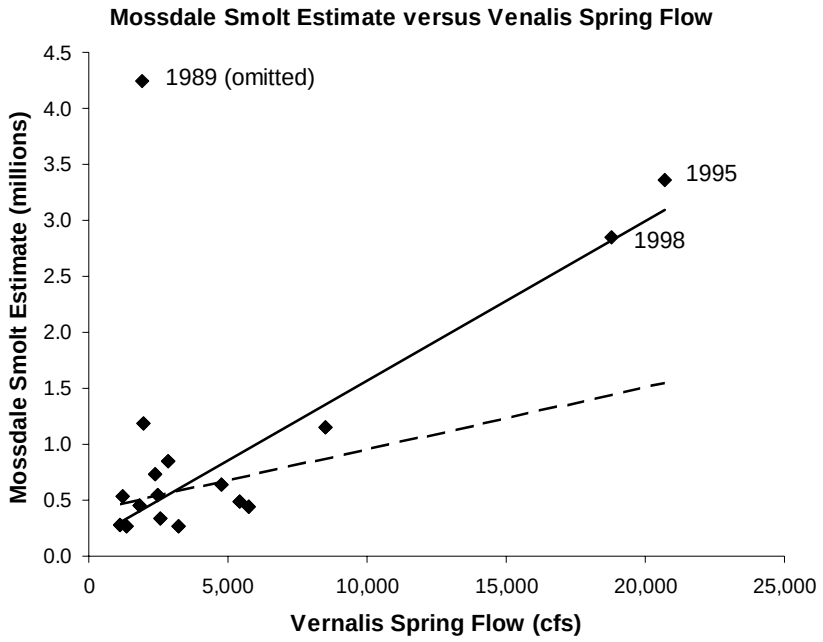


Figure 4. Mossdale smolt estimates as a function of Vernalis spring flow. The solid line is the regression line using all data except 1989. The dashed line is the regression with 1995, 1998, and 1989 omitted.

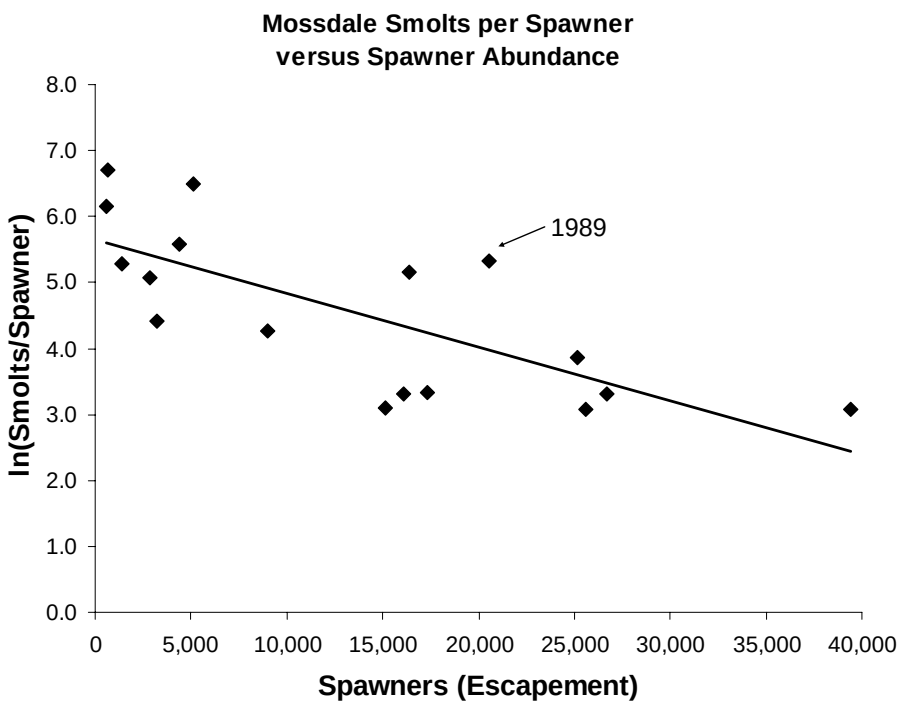


Figure 5. Mossdale smolts per spawner as a function of spawner abundance (escapement). Data are presented in Table 1. The declining trend suggests evidence of density dependence.

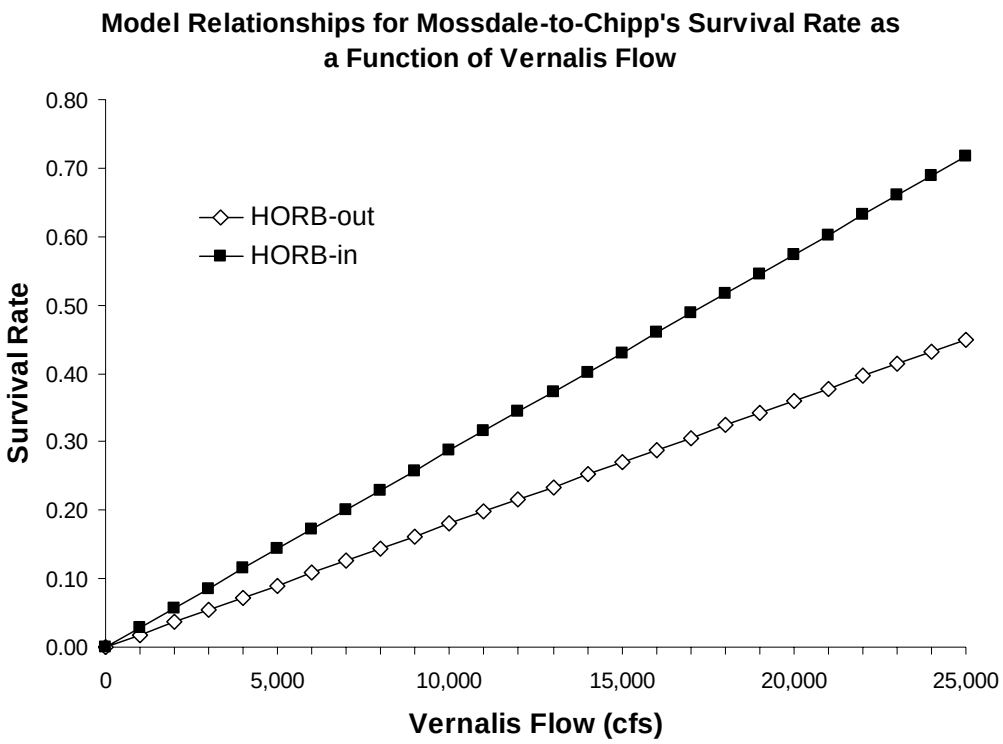


Figure 6. Relationships used in the CDFG model to predict smolt survival rate between Mossdale and Chipp's Island as a function of Vernalis flow.

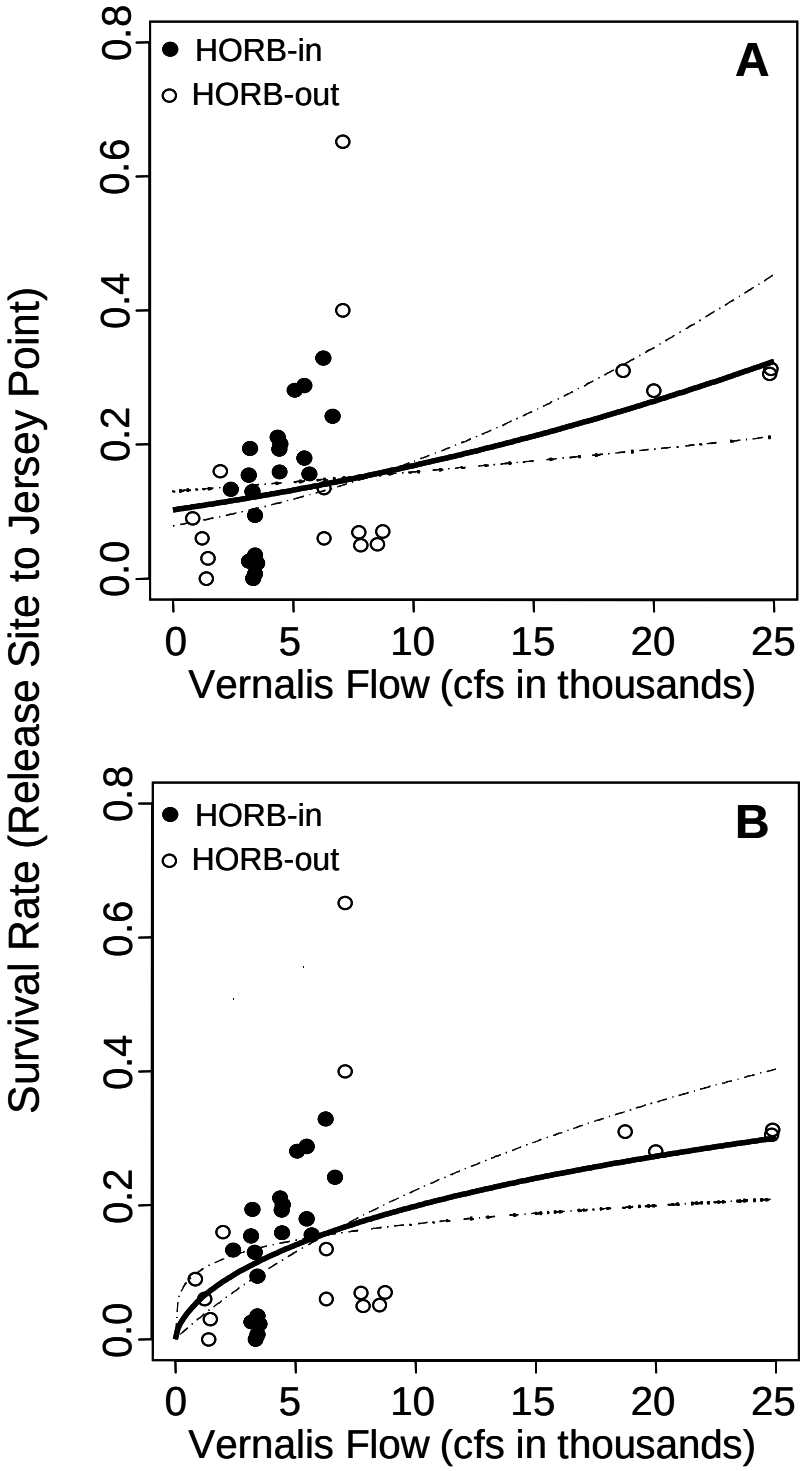


Figure 7**.** Two forms of the flow-survival relationship for migrating smolts in the lower San Joaquin River (delta) estimated using logistic regression: **(A)** survival versus flow; and **(B)** survival versus ln(flow). Dashed lines indicate approximate 95% confidence intervals for the shape of a given flow-survival relationship.

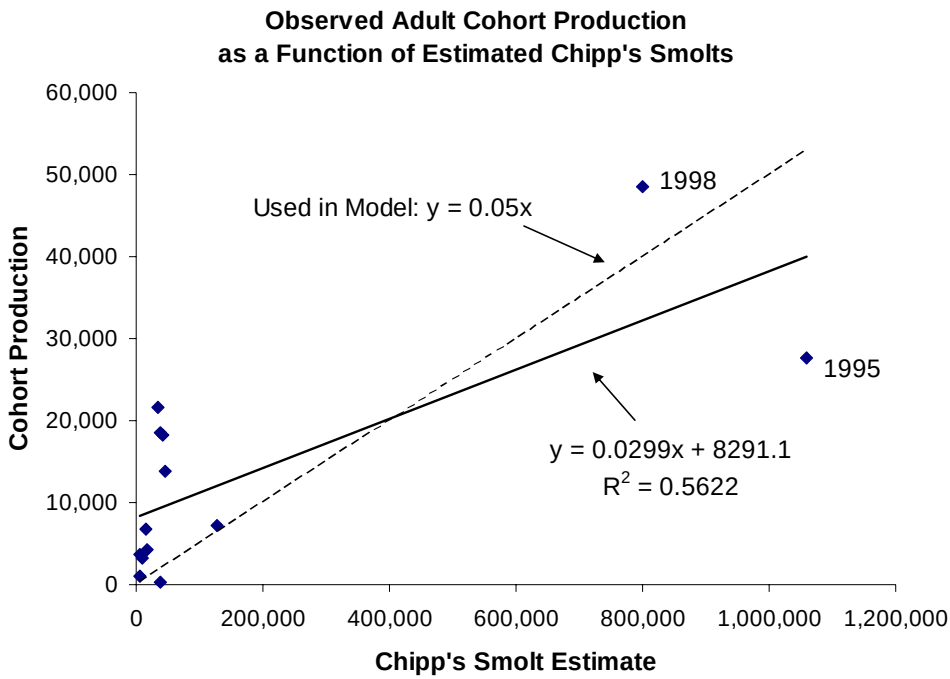


Figure 8. Linear regression of observed adult cohort production versus estimated Chipp's smolt abundance used by CDFG (2005; see their Figure 36). Solid line is the linear regression without constraining the Y-intercept. Dashed line is the "calibrated" relationship used in the model (Y-intercept = 0 and "Chipp's smolt marine survival" = 0.05 or 5%).

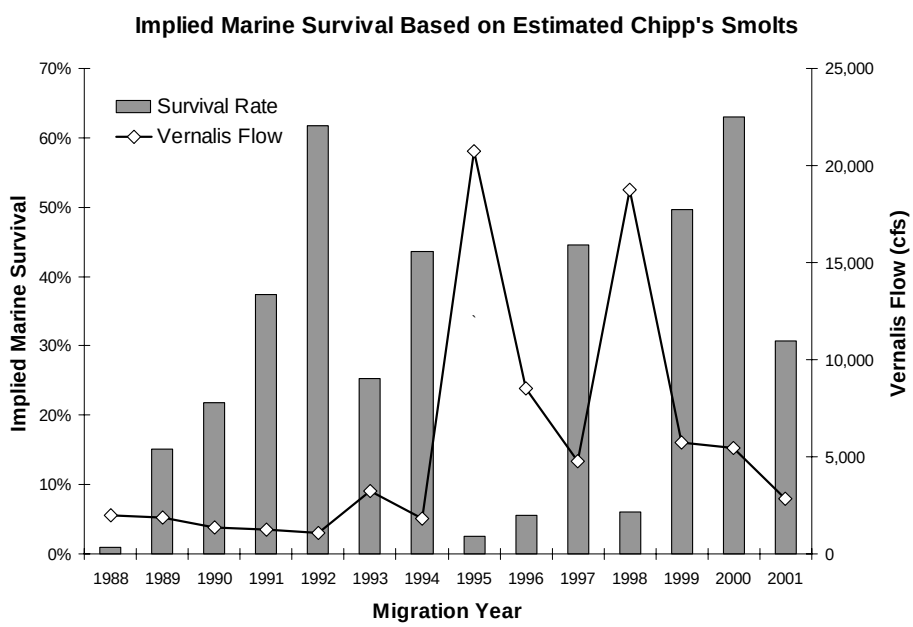


Figure 9. Implied marine survival by migration year given CDFG model estimates of Chipp's smolts and observed values of cohort production. Also shown are average Vernalis spring flows by migration year.

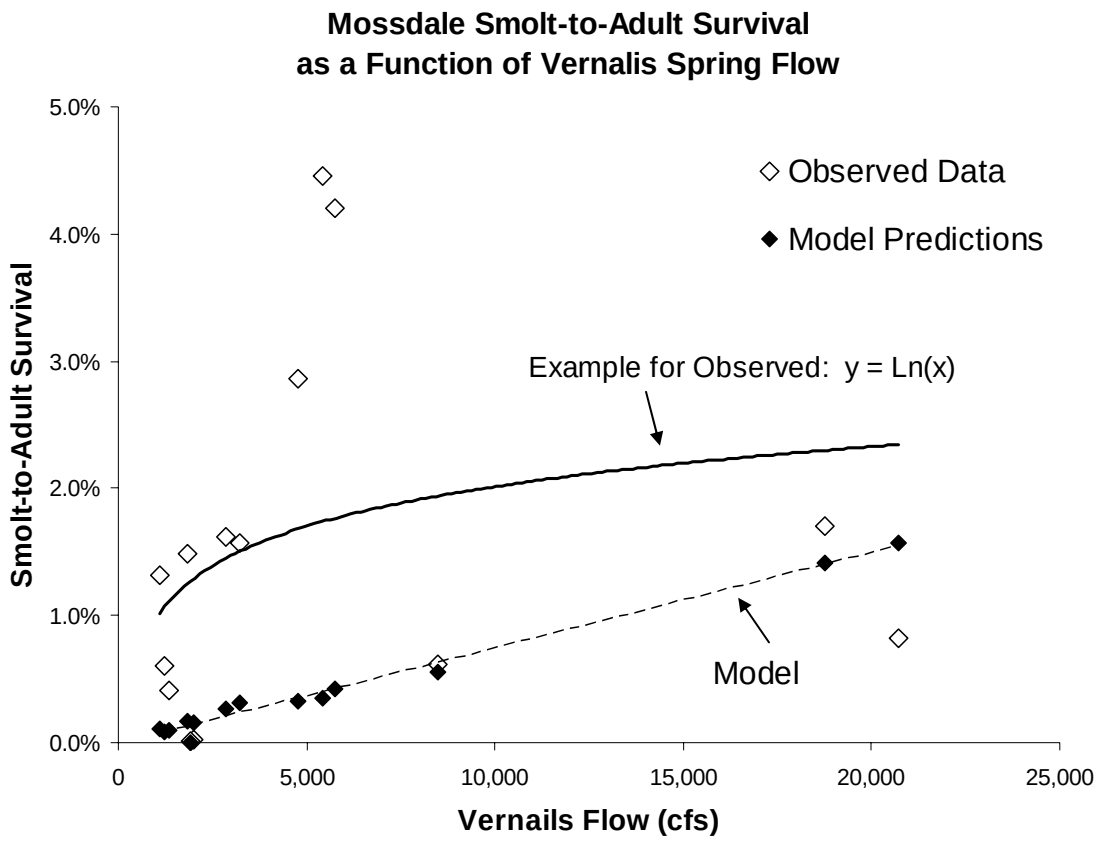


Figure 10. Observed and predicted values of Mossdale smolt-to-adult survival as a function of Vernalis spring flow (data from Table 1 and CDFG model files). The solid line depicts an example trend line for the observed data of the form: survival = ln(flow). The dashed line depicts the general linear relationship between model predictions and flow.

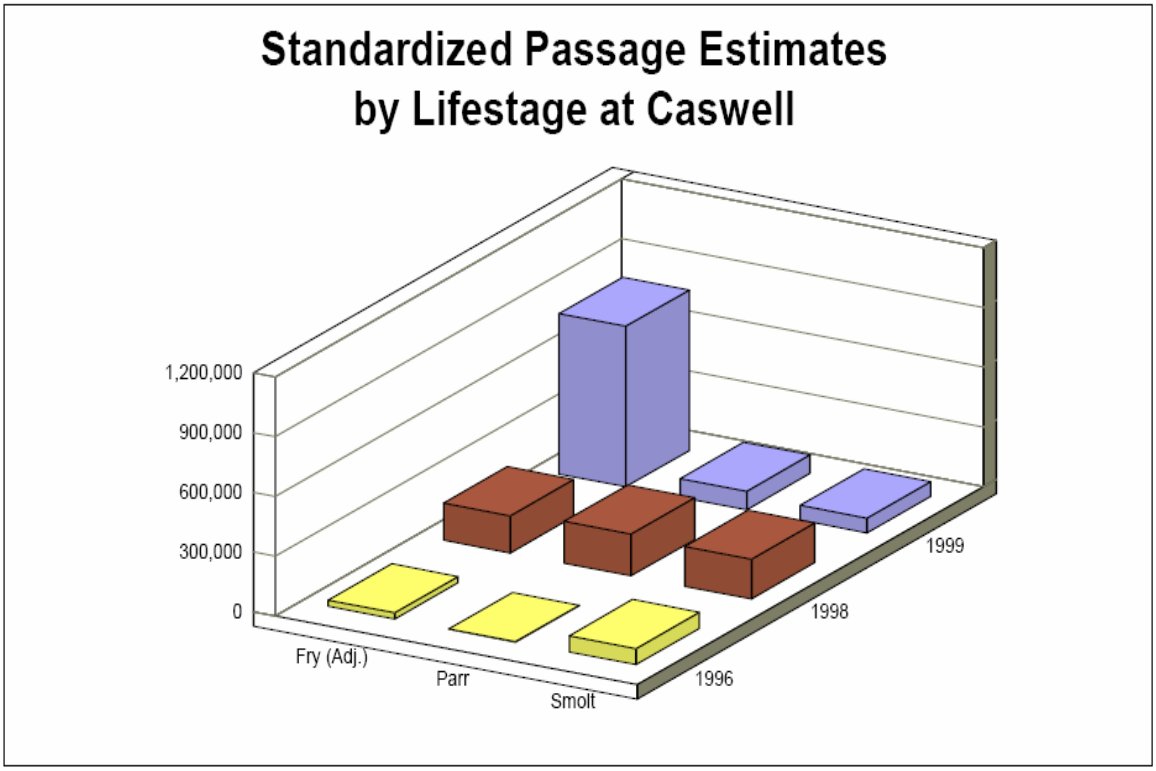
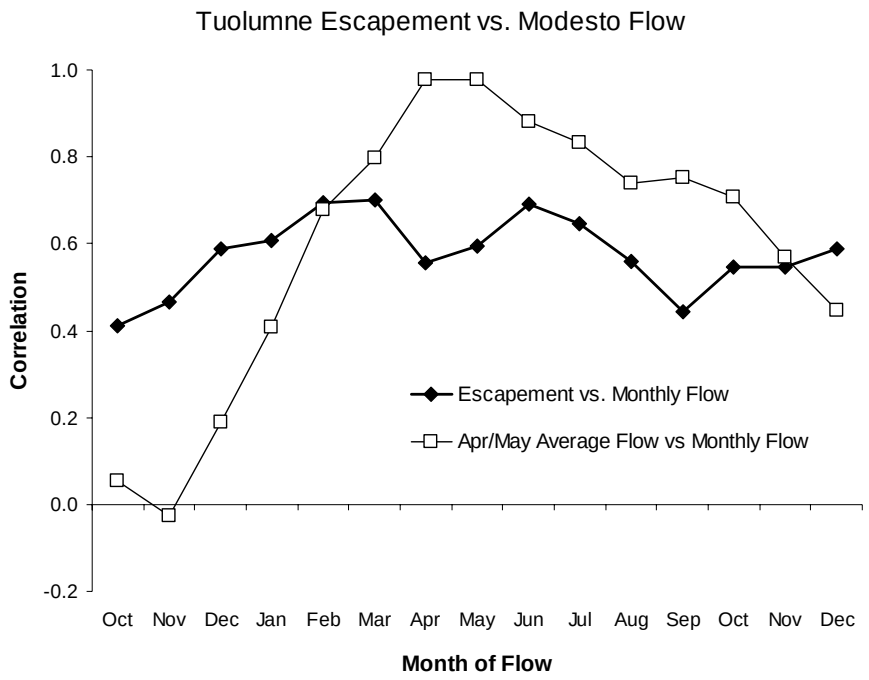


Figure 11. Estimates of juvenile Chinook passing Caswell Park (RM 9) on the Stanislaus River during 1996, 1998, and 1999. From Demko et al. (2000).



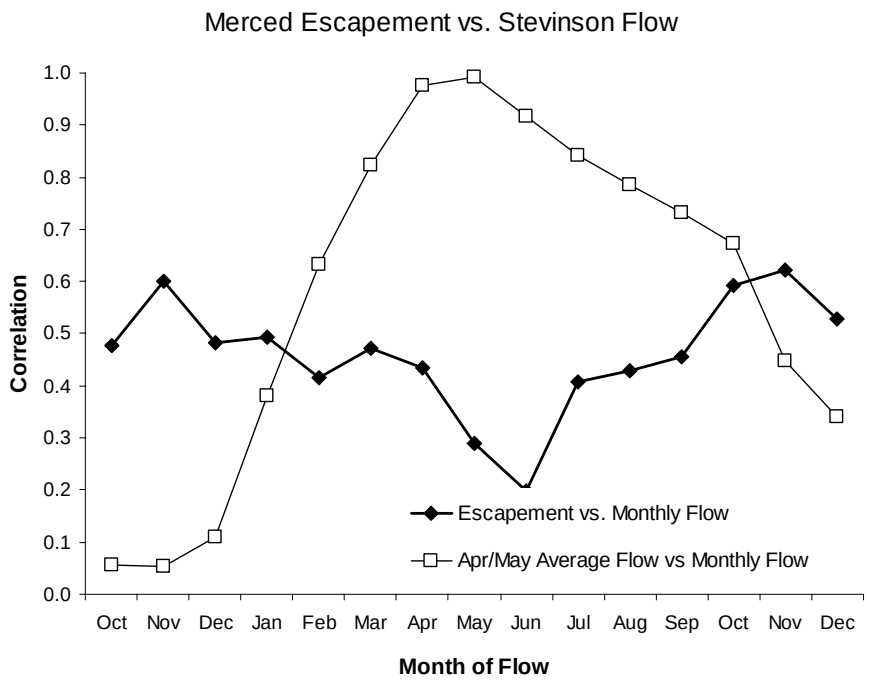
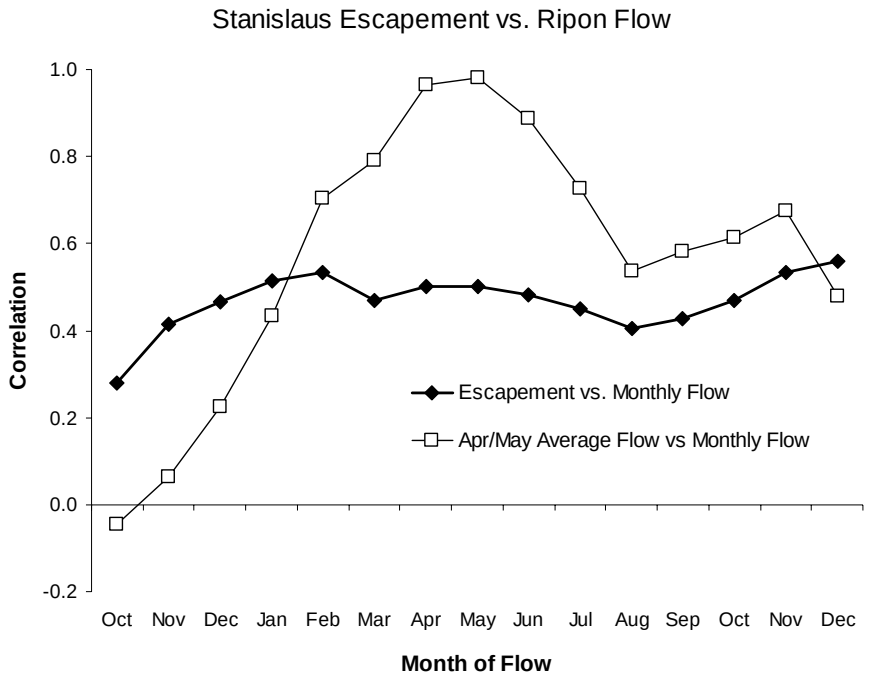


Figure 12. Correlations between escapement and monthly flow, and between April-May average flow and monthly flow, for the Tuolumne and Merced Rivers.



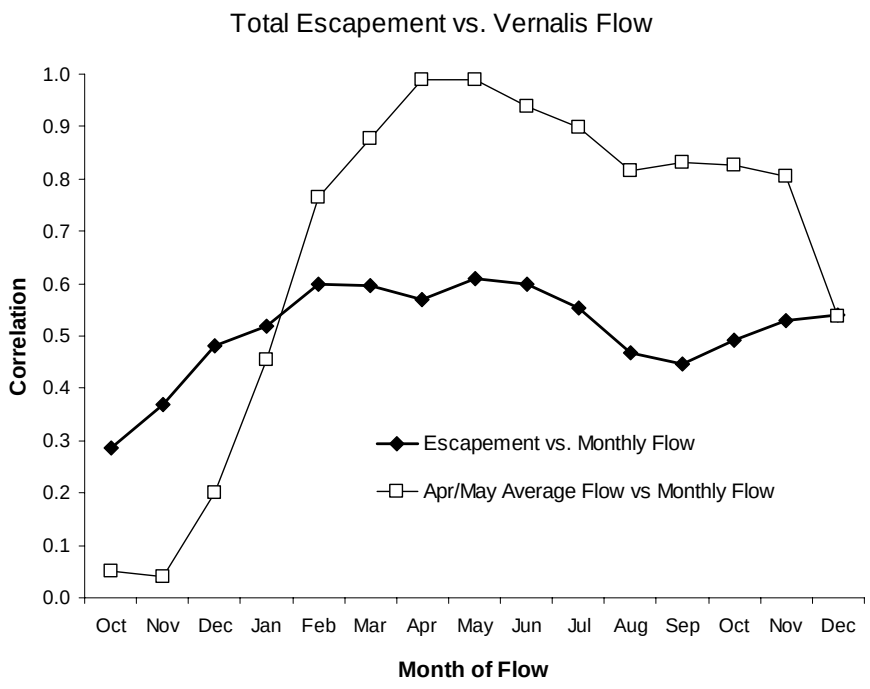


Figure 13**.** Correlations between escapement and monthly flow, and between April-May average flow and monthly flow, for the Stanislaus River and for total SJR escapement versus Vernalis flow.

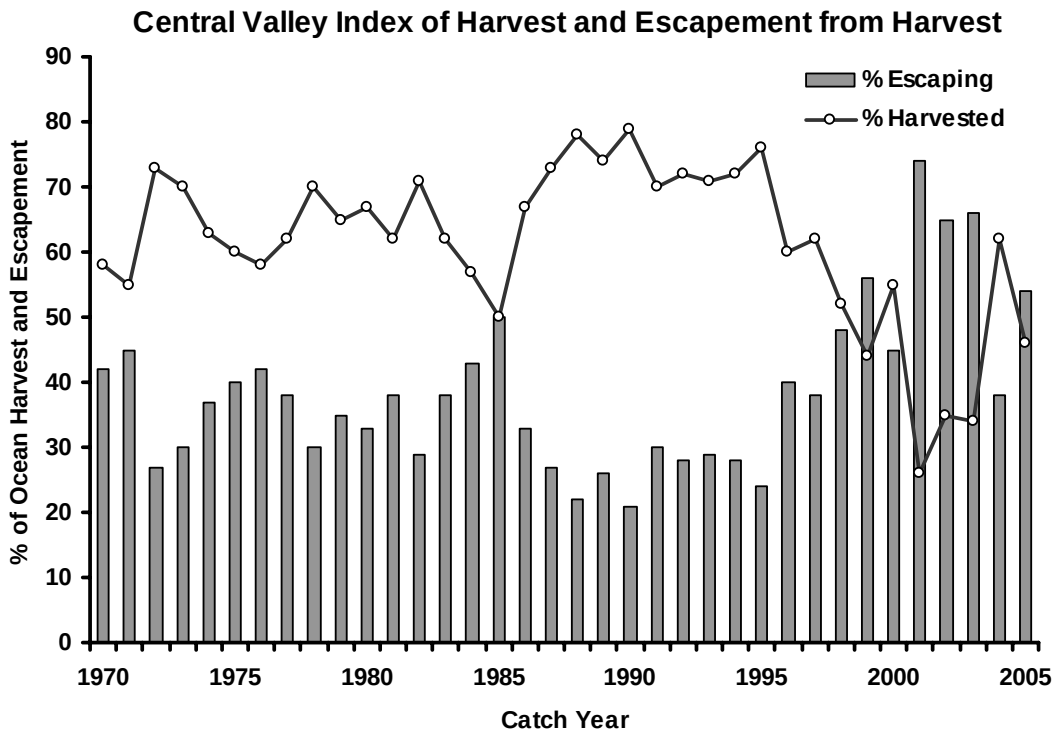


Figure 14**.** Central Valley Index (CVI) of ocean harvest rate for Chinook salmon, 1970- 2005. Also shown is the implied fraction of adults escaping harvest which is equal to 1 – CVI.