ESTIMATING
POPULATION LEVEL AND WATER SUPPY EFFECTS
OF DELTA WATER PROJECT ACTIONS

William J. Miller
February 27, 2002

CONTENTS

ESTIMATING POPULATION LEVEL AND WATER SUPPY EFFECTS OF DELTA WATER PROJECT ACTIONS

William J. Miller

February 27, 2002

INTRODUCTION

Each year, actions are taken to change the operation of the State Water Project and federal Central Valley Project in the Sacramento-San Joaquin Delta of California. (See Location map in Appendix C) Although the intent of these actions is to increase fish populations, estimates of the population level effects of these actions have not been made. The actions consist of the following:

- Increases in the flow of water out of the Delta into San Francisco Bay, accomplished by increasing releases from upstream reservoirs and/or curtailing exports from the southern Delta by the two projects.
- Increases in the flow of water into the Delta from the Sacramento or San Joaquin Rivers, accomplished by increasing releases from upstream reservoirs
- Closing of the Delta Cross Channel gates or installation of a barrier at the head of Old River, both of which are intended to prevent fish from leaving the main stem rivers and entering side channels.
- Curtailment of exports to reduce mortality at the export pumps.

This paper presents methods of estimating the population level effects. Each method uses the same general approach, which can be described as follows: Over the years, the Interagency Ecological Program has collected data on the survival or abundance of various fish. These data were collected under a variety of conditions of Delta outflow, Delta inflow, Cross Channel gate positions, Old River barrier installations, and export rate. Other variables such as temperature and salinity were also measured. Correlations have been developed from these data. The correlations relate survival of outmigrating salmon smolts or abundance of other fish to values of the above-listed parameters. Using these correlations, estimates can be made of the expected changes in survival or abundance for any change in one or more of these conditions.

Abundance measures occur in two forms, actual abundance, that is, the number of individuals present, and abundance indices, which are measures of relative abundance. The percent change in actual abundance or in the abundance index is a direct measure of the percent change in population size.

For salmon, the above-mentioned correlations relate survival of outmigrating smolts through the Delta to various conditions in the Delta. The percent change in survival through the Delta is equal to the percent change in population size of smolts that survive the Delta and enter San Francisco Bay. If all other factors affecting salmon survival to adulthood are equal, including a lack of density dependence downstream of the Delta, this percent change in survival through the Delta is a measure of the percent change in adult population.

Estimates of fish population changes derived by this method are "expected" or "average" values in the statistical sense. Estimates of the variability in these values are also given. It is possible that the results of a particular action in the future may not be "average" or even within the range shown, especially if conditions are different from those prevailing when the data on which the correlations are based were collected.

Note that for salmon smolts, because of the way the smolt survival experiments were conducted, these estimates account for both "direct" and "indirect" mortality. Direct mortality is mortality occurring within the pumping facilities, including approach channels and Clifton Court Forebay at the Banks Pumping Plant. Indirect mortality is that mortality occurring in the Delta, outside of the pumping facilities, that is attributable to export pumping.

For this paper, estimates of fish population changes are calculated in Excel spreadsheets, one for each species. Examples of the spreadsheets are shown below. Appendix A shows the functions that must be entered in these spreadsheets to produce the estimates. These spreadsheets can be downloaded from www.sldmwa.com or obtained by emailing bjmill@aol.com. Appendix A also includes key assumptions underlying each spreadsheet, instructions for changing those assumptions, and the effect of such changes on the population estimates.

Appendix B shows the data on which the spreadsheets are based, except for Sacramento fall run salmon. For this race of salmon, reference must be made to a paper by Dr. Ken Newman (Newman 2000). All data were collected by the Interagency Ecological Program.

If more data become available, these spreadsheets can be modified, except for the Sacramento fall run spreadsheet, which would require a repeat of the statistical analysis by Prof. Ken Newman. However, Newman's analysis used the results of about 60 sets of paired data, so a few additional data points would not be expected to have much effect on his results. To change the other spreadsheets, add the new data to the data tables in Appendix B. Redo the statistical correlations. Obtain new coefficients for the intercept and slope relative to the variable of interest. Insert these new coefficients into the cells in the spreadsheets, replacing the old coefficients.

To use the spreadsheets, data must be entered in the shaded cells. These data consist of the initial conditions, conditions produced by the protective action, and duration of the action. Depending on the species, other data such river flow and the percent of the population affected by the action may also be required. The spreadsheets calculate estimates of population level change and water required by the action.

For the examples used in this paper, conditions were set to make the water cost roughly 100,000 acre feet for each example. This facilitates comparisons of the effectiveness of actions for different species. The cost of 100,000 acre feet of water varies from year to year and location to location, but based on recent transactions, a price of $100 per acre-foot is representative (Johnson 2001). Using this price, the cost of 100,000 acre feet of water would be $10 million. This amount of money can be compared with the cost of other actions that might be taken to increase fish populations.

Note that this water cost does not include the possibility that the water might be made up at some other time. It is not unusual that, for example, if an export curtailment reduces storage south of the Delta, this loss of stored water can be replenished later.

SACRAMENTO RIVER FALL RUN SALMON SMOLTS

DEVELOPMENT OF SPREADSHEETS TO ESTIMATE POPULATION LEVEL EFFECTS

Newman developed a number of correlation equations relating survival of fall run smolts passing through the Delta to various factors. We used his three "best" correlations, which were all roughly equal in the statistical sense. That is, they described the relationships inherent in the data equally well.

Three tables are presented below as examples of the spreadsheets based on these three correlation equations.

The first table is an example of the spreadsheet relating smolt survival to both export rate and Cross Channel gate position. The second table is an example of the spreadsheet relating smolt survival to export rate but not Cross Channel gate position. The third table is an example of the spreadsheet relating smolt survival to Cross Channel gate position but not export rate.

These three tables are examples of an action consisting of an export curtailment from 8,000 cfs to 4,000 cfs for 14 days when Sacramento River flow is 16,000 cfs and 15 percent of the outmigrating smolts are passing through the Delta.

Each spreadsheet produces a different estimate of the population effect. We might consider the 4.4 percent estimate from the first spreadsheet, relating survival to both export rate and Cross Channel position, to be a "mid-range" estimate. However, the estimates from the other two spreadsheets, 11.6 percent and 0.0 percent, are just as likely to be correct.

95 percent confidence limits could not be estimated from these data, but estimates from all three spreadsheets provide some perspective on the range of confidence.

In each spreadsheet, the water cost directly attributable to this action is 110,880 acre-feet. This is calculated as the product of 4,000 cfs (8,000-4,000), 14 days, and a factor (1.98) to convert cfs-days to acre-feet. Note that this water cost may not reduce water supplies by 110,880 acre-feet if the foregone exports can be made up at another time.

Fall Run Salmon Smolt Survival
vs. Export Rate and Cross Channel Position

Conditions	Sacramento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Duration of Action days	Outmigrants Affected % of Total	Survival through Delta	Increase in Pop'n %	95% Confidence Limits for Pop'n Increase	Additional River Flow Required acre-feet	Exports Fore-gone acre-feet
Initial	16,000	8,000	0	14	15	0.61	**4.4**	see other tables	**0**	**110,880**
Final	16,000	4,000	0			0.79		see other tables		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

Fall Run Salmon Smolt Survival
vs. Export Rate but not Cross Channel Position

Conditions	Sacramento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Duration of Action days	Outmigrants Affected % of Total	Survival through Delta	Increase in Pop'n %	95% Confidence Limits for Pop'n Increase	Additional River Flow Required acre-feet	Exports Fore-gone acre-feet
Initial	16,000	8,000	0	14	15	0.34	**11.6**	see other tables	**0**	**110,880**
Final	16,000	4,000	0			0.59		see other tables		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

Fall Run Salmon Smolt Survival
vs. Cross Channel Position but not Export Rate

Conditions	Sacramento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Duration of Action days	Outmigrants Affected % of Total	Survival through Delta	Increase in Pop'n %	95% Confidence Limits for Pop'n Increase	Additional River Flow Required acre-feet	Exports Fore-gone acre-feet
Initial	16,000	8,000	0	14	15	0.73	**0.0**	see other tables	**0**	**110,880**
Final	16,000	4,000	0			0.73		see other tables		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

BASIS OF THE SPREADSHEETS USED TO ESTIMATE POPULATION CHANGE AND WATER COST

Ken Newman analyzed data provided by Pat Brandes, US Fish and Wildlife Service (Newman 2000). These data were obtained from experiments in which hatchery-grown, coded wire tagged fall run salmon smolts were released upstream of or in the Delta and recaptured downstream.

Newman developed a number of equations describing the relationship between outmigrating smolt survival through the Delta and several factors, including river flowrate, export rate, and Cross Channel position. The three "best" equations, in a statistical sense, were used to create the three spreadsheets shown in Appendix A.

The three equations are each of the same form: Survival = e^B / (1+e^B) where e^B means e raised to the power B.

The equation for B varies depending on which of the three best equations is used. For the spreadsheets, the three equations are, respectively:

$$B = -34.05 + 3.69 \ln(\text{SacFlow}) + 0.000152 \text{ Salinity} - 0.000219 \text{ Exports} - 0.87 \text{ Gate}$$

$$B = -32.6 + 3.47 \ln(\text{SacFlow}) + 0.000128 \text{ Salinity} - 0.000266 \text{ Exports}$$

$$B = -27.3 + 2.88 \ln(\text{SacFlow}) + 0.000117 \text{ Salinity} - 1.02 \text{ Gate},$$

where "ln" indicates natural log, SacFlow and Exports are in cfs, Gate = 0 when the Cross Channel gates are closed and 1 when they are open, and Salinity is electrical conductivity in micro mho/cm at Collinsville. Salinity can be estimated using the following equations developed from data presented by Newman and Rice (Newman 1997).

$$\text{Salinity} = 75{,}231 - 7{,}405 \ln(\text{SacFlow}) \text{ for SacFlow} < 27{,}000 \text{ cfs},$$

and

$$\text{Salinity} = 707 - 47.8 \ln(\text{SacFlow}) \text{ for SacFlow} > 27{,}000 \text{ cfs}.$$

ASSUMPTIONS

Assumptions for this analysis are listed below. Instructions for modifying the three spreadsheets to reflect changes in each assumption are shown in Appendix A.

1. **The number of adult salmon produced from these smolts is proportional to the number of smolts surviving passage through the Delta.** Conditions downstream of the Delta can affect the ratio of smolts to adults. These conditions include predation rates and

ocean conditions. Of particular concern are "density dependent" conditions (such as insufficient food) that limit the number of adults, regardless of the number of smolts above a certain minimum level. The assumption of no density dependence tends to produce an upper estimate of population change.

2. **Actions whose population effects are being estimated are occurring within the range of conditions under which the original data were collected.** If conditions are outside this range, the correlations may no longer apply. If there were good reasons to expect estimates of population effects to be greater or less than predicted by the spreadsheets, adjustments could be made to the predicted results.

3. **The fraction of total fall run outmigrants passing through the Delta during the action period can be estimated.** Data from past years' upstream or Delta sampling might provide some insight in estimating this fraction. It might also be instructive to try different reasonable values for this fraction to see how large it would have to be to produce important results relative to the amount of water required.

4. **The amount of water required could not be made up at some other time**. Sometimes, export curtailments can be offset by increasing the rate of export pumping at another time. Extra river flows or Delta outflow might require reservoir releases that are of no consequence if the reservoir fills later in the year.

LATE FALL, SPRING, AND WINTER RUN SALMON SMOLTS

DEVELOPMENT OF SPREADSHEETS TO ESTIMATE POPULATION LEVEL EFFECTS

The table below is an example of the spreadsheet based on December-January experiments on the effect of export rate on salmon smolt survival. For these experiments survival is expressed as the ratio of survival of smolts released into the northern end of Georgiana Slough to the survival of smolts released at essentially the same time into the Sacramento River just downstream of Georgiana Slough, at Ryde. Use of this ratio eliminates some of the confounding variables inherent in the measurement of survival and provides more stable data.

If we set aside disputes over the validity of these data, a straight line of the following form can be fit to these data:

S_{Geor}/S_{Ryde} = a + b*Exports

Where

S_{Geor} = survival from the northern end of Georgiana Slough to Chipps Island, and
S_{Ryde} = survival from Ryde to Chipps Island, and
Exports = the total export rate in cfs at the Banks and Tracy Pumping plants.

To estimate survival through the Delta, we need a relationship between export rate and survival from Sacramento to Chipps Island. Therefore, the relationship between S_{Geor}/S_{Ryde} and export rate must be transformed. We transformed this relationship as follows:

Let "N" be the number of smolts passing Sacramento. Assume that none of these smolts enter Sutter and Steamboat Sloughs and that all of these smolts survive to the Delta Cross Channel and the north end of Georgiana Slough. A fraction of these smolts enter the Delta Cross Channel (if the gates are open) and Georgiana Slough. The fraction of smolts entering these channels has been related to the fraction of flow entering (Hanson 1994 and 1995).

The fraction of Sacramento River flow entering the Cross Channel and Georgiana Slough can be estimated from equations used in DAYFLOW (DWR 2001). These equations are

Flow entering the Cross Channel and Georgiana Slough = 0.293*Q_{Sac} + 2,090 cfs, if the Cross Channel gates are open, and

Flow entering Georgiana Slough = 0.133 Q_{Sac} + 829 cfs, if the Cross Channel gates are closed,

Where Q_{Sac} = flow in the Sacramento River in cfs.

Dividing these equations by Q_{Sac} yields the fraction of flow entering these channels, namely,

> Fraction of Sacramento River flow entering the Cross Channel and Georgiana Slough = 0.293 + 2,090 cfs/Q_{Sac}, if the Cross Channel gates are open, and
>
> Fraction of Sacramento River flow entering Georgiana Slough = 0.133 + 829 cfs/Q_{Sac}, if the Cross Channel gates are closed.

Hanson (Hanson 1994 and 1995) found that the ratio of the fraction of smolts entering these two channels to the fraction of water entering these channels was 0.58. We will denote this fraction by "f."

Therefore, the fraction of smolts entering these channels is as follows:

> f*(0.293 + 2,090 cfs/Q_{Sac}) if the Cross Channel gates are open, and
>
> f*(0.133 + 829 cfs/Q_{Sac}) if the Cross Channel gates are closed.

The fraction of smolts remaining in the Sacramento River is 1.0 minus the above two fractions.

Denote the survival of smolts from Ryde to Chipps Island as "s." A reasonable estimate for this fraction is 0.8 (Greene 2000). Then, the number of smolts reaching Chipps Island via the Sacramento River is the product of "N," the fraction remaining in the Sacramento River, and "s."

If the survival from Ryde to Chipps is "s," the survival from the north end of Georgiana to Chipps Island is as follows:

> S_{Geor} = s*(a + b*Exports).

The number of smolts reaching Chipps Island via the Delta Cross Channel and Georgiana Slough is the product of "N," the fraction entering those channels, and the survival of that fraction.

Therefore, the total number of smolts reaching Chipps Island is the sum of the number reaching Chipps Island via the Sacramento River and the number reaching Chipps Island via the Delta Cross Channel and Georgiana Slough. If this sum is divided by "N," the number of smolts passing Sacramento, the overall survival from Sacramento to Chipps Island can be expressed as a function of export rate. (The variable "N" is a factor of both the numerator and denominator and disappears from the ratio).

The assumptions used in this transformation are listed below and their effects on the estimates of population change are described in Appendix A.

The table below illustrates effects of a protective action identical to the one shown above for fall run salmon, except this action could be occurring in a different time of the year. It consists of an export curtailment from 8,000 to 4,000 cfs for 14 days affecting 15 percent of the outmigrants when Sacramento River flow is 16,000 cfs.

Note that the water cost is the same as in the example for fall run salmon above. However, the population change is only 0.2 percent. In this case, 95 percent confidence limits could be estimated; we can say that there is a 95 percent probability that the interval, 0.26 percent to 0.65 percent, bounds the true value of the population change.

Spring Run, Late Fall Run, and Winter Run Salmon Smolt Survival vs. Sacramento River Flow and Export Rate

Conditions	Sacramento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Fraction of Smolts Entering DCC & Geor. Sl./Fraction of Water Entering	Survival from Ryde to Chipps	Survival	Duration of Action days	Estimated Outmigrants Affected % of Total
Initial	16,000	8,000	0	0.58	0.8	0.74	14	15
Final	16,000	4,000	0			0.75		

Increase in Population %	95% Confidence Limits for Population Increase %	Additional River Flow Required acre-feet	Exports Foregone acre-feet
0.2	**0.26**	**0**	**110,880**
	0.65		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

ASSUMPTIONS

The assumptions for Sacramento River fall run smolts in the first section of this paper also apply for this species and are repeated below. Additional assumptions also apply. The effect of these assumptions is discussed in Appendix A:

1. **The number of adult salmon produced from these smolts is proportional to the number of smolts surviving passage through the Delta.** See the discussion above for fall run salmon. Density dependence downstream of the Delta is less likely for these races of salmon because their population numbers are lower than those for fall run salmon.

2. **Actions whose population effects are being estimated are occurring within the range of conditions under which the original data were collected.** If conditions are outside this range, the correlations may no longer apply. If there were good reasons to expect estimates of population effects to be greater or less than predicted by the spreadsheets, adjustments could be made to the predicted results.

3. **The fraction of total fall run outmigrants passing through the Delta during the action period can be estimated.** Data from past years' upstream or delta sampling might provide some insight in estimating this fraction. It might also be instructive to try different reasonable values for this fraction to see how large it would have to be to produce important results relative to the amount of water required.

4. **The amount of water required could not be made up at some other time**. Sometimes, export curtailments can be offset by increasing the rate of export pumping at another time. Extra river flows or Delta outflow might require reservoir releases that are of no consequence if the reservoir fills later in the year.

5. **Survival from Ryde to Chipps Island is 0.8**, a generally accepted value (Greene 2000). This survival estimate can be changed or made a function of one or more factors such as temperature and salinity.

6. **The fraction of Sacramento River flow entering Georgiana Slough or the Cross Channel (if open) can be estimated from the equations used in Dayflow**, the Department of Water Resources method of accounting for Delta flow (DWR 2001).

7. **The ratio of the fraction of smolts entering Georgiana Slough and the Cross Channel is 0.58 of the fraction of water entering either of those channels.** (Hanson 1994, Hanson 1995)

8. **No smolts that pass the City of Sacramento enter Steamboat or Sutter Sloughs.** This is an environmentally conservative assumption because smolts entering these two sloughs are not affected by export rate.

9. **That the smolt survival experiments can also be used to estimate survival of outmigrating winter run salmon** (Pat Brandes, US Fish and Wildlife Service).

LONGFIN SMELT AND STARRY FLOUNDER

DEVELOPMENT OF SPREADSHEETS TO ESTIMATE POPULATION LEVEL EFFECTS

Abundance of these two species has been correlated with the average springtime value of X2, the distance from the Golden Gate Bridge to the location along the main channel where near-bottom salinity is 2 ppt. The value of X2 is largely controlled by the rate of outflow from the Delta. X2 is, therefore, highly correlated with Delta outflow. (Schubel 1993)

The 1986 invasion of the Asian clam, *Potamocorbula amurensis*, substantially changed the food web in the area of the western Delta and Suisun Bay. (Hollibaugh 1996). By 1988 these thumbnail-sized clams reached densities of more than 40,000 per square meter on the bed of the estuary (Peterson 1996) and were daily filtering a significant amount of the water overlying them (Hollibaugh 1991). As a result of grazing by this clam, the relationships between X2 and abundance changed for several species. Generally the effect was to lower abundance for any particular value of X2 and to change the slope of the regression line.

Abundance of a number of species had been correlated with X2 or Delta outflow prior to the clam's arrival. Newman reanalyzed these relationships using data up to and including year 2000. (Newman 2001a)

First, he determined whether there was a statistically significant difference in the abundance/X2 relationships (in their slope or intercept) between the pre- and post-clam periods. He found such a difference for american shad, longfin smelt, and striped bass (fall midwater trawl abundance index). There was a borderline difference for caridean shrimp, Pacific herring, and starry flounder (one-year olds). There was no difference for Crangon shrimp, delta smelt, splittail, and striped bass larval survival.

For those species without a difference, he correlated abundance with X2 using data from all years, pre- and post-clam. For those species with a difference, he correlated abundance with X2 using the post-clam data. For those species with a borderline difference, he correlation abundance with X2 using all data and using only post-clam data.

For those species showing statistically significant correlations, we screened out those that did not involve adult fish. We also screened out splittail because the more fundamental relationship is between abundance and inflow. (See the next section for the analysis of splittail abundance vs. Delta inflow.) We screened out Crangon shrimp because Crangon is just one of several species of caridean shrimp, all of which occupy the same ecological niche (Hieb 1988), so the relationship between crangon and X2 just reflects the relative distribution of these different species of shrimp. Newman also tested the correlation between caridean abundance and X2 in post-clam years.

The "X2 species" are listed below along with the rationale for including or not including them in this population estimation methodology:

Longfin smelt: The abundance/X2 relationship shows a statistically significant difference in the pre- and post-clam periods. Abundance has a statistically significant correlation with X2 in the post-clam period. Therefore, population estimates for this species are analyzed in this paper.

American shad: The abundance/X2 relationship shows a statistically significant difference in the pre- and post-clam periods. Abundance does not have a statistically significant correlation with X2 in the post-clam period (p value substantially more than 0.10). Therefore, population estimates for this species are not analyzed in this paper.

Crangon shrimp: The abundance/X2 relationship does not show a statistically significant difference in the pre- and post-clam periods. Abundance has a statistically significant correlation with X2. However, the relationship for crangon shrimp appears to be simply distributional in nature. Crangon is one species of caridean shrimp. All species of caridean shrimp serve the same role in the food chain (Kathy Hieb, California Department of fish and Game, 1998, remarks at the spring 1998 X2 workshop at the Contra Costa Water District). However, the relative abundance of caridean shrimp species varies with Delta outflow. In other words, as the abundance of crangon shrimp goes down, the abundance of another caridean shrimp increases. Therefore, population estimates for this species are not analyzed in this paper.

Striped bass larval survival: Larval survival is the ratio of summer young-of-the-year abundance to egg abundance (estimated from previous year's adult abundance). The abundance/X2 relationship does not show a statistically significant difference in the pre- and post-clam periods. Abundance has a statistically significant correlation with X2 using all data. However, even though there appears to be a relationship between one year's fall midwater trawl abundance index and the next year's, there is no statistically significant relationship between larval survival and adult abundance. Therefore, population estimates for this species are not analyzed in this paper.

Striped bass fall midwater trawl abundance index: The abundance/X2 relationship shows a statistically significant difference in the pre- and post-clam periods. Abundance does not have a statistically significant correlation with X2 in the post-clam period (p value substantially more than 0.10). Therefore, population estimates for this species are not analyzed in this paper.

Pacific herring: The abundance/X2 relationship shows a marginally statistically significant difference in the pre- and post-clam periods. Abundance does not have a statistically significant correlation with X2 using data from the post-clam period or from all years (p value substantially more than 0.10). Therefore, population estimates for this species are not analyzed in this paper.

Splittail: The abundance/X2 relationship shows no statistically significant difference in the pre- and post-clam periods. Abundance has a statistically significant correlation with X2 using data from all years. However, it is now generally acknowledged that this correlation is really with Delta inflow during the spawning period (Moyle 2001). Delta inflow is strongly correlated with Delta outflow; hence, the correlation with X2, which is largely determined by Delta outflow. Population estimates for splittail, based on Delta inflow, are addressed in the next section of this paper.

Starry flounder: The abundance/X2 relationship shows a marginally statistically significant difference in the pre- and post-clam periods. Abundance has a marginally (p value = 0.11) statistically significant correlation (p value = 0.11) with X2 in the post-clam period and a statistically significant correlation using all years of data. Therefore, population estimates for this species are analyzed in this paper.

Neomysis Mercedes: This is not an adult fish species. Its abundance does not correlate with the abundance of any adult fish species. Therefore, it is not included in this paper. Incidentally, it does not have a statistically significant relationship with X2 in the post-clam period.

The abundance vs. X2 relationships are of the form

$$\mathrm{LOG(Abundance)} = a(X2) + b,$$

Where a and b are constants, abundance is the annual abundance in the same year as X2, and X2 is the average value of X2 during the critical period (a number of sequential months in the spring) for each species. However,

$$X2 = m*\mathrm{LOG(Delta\ outflow)} + n,$$

Where m and n are constants, and Delta outflow is the average Delta outflow during the critical period for each species. For convenience, we can express abundance as a function of Delta outflow as follows:

$$\mathrm{LOG(Abundance)} = k_1*\mathrm{LOG(Delta\ Outflow)} + k_2,$$

Where k_1 and k_2 are constants.

The tables below are examples of the spreadsheets based on correlations using the above equation. The data and statistical analyses are shown in Appendix B. Abundance and X2 data for species whose abundance is not estimated in this paper can be found in the Newman report (Newman 2001a).

The conversion from X2 to average outflow can be made by using the steady state form of the equation on page A-8 of Schubel (Schubel 1993):

$$X2 = [122.2 - 17.65*LOG_{10}(\text{Delta outflow, cfs})]/0.6722$$

Each table below shows the population level effect of a 14-day increase in Delta outflow, from 10,000 cfs to 14,000 cfs. The critical period is the number of days in the months during which X2 or Delta outflow is thought to be important for each species. The critical period is the same critical period in the original analysis by Jassby et al (Jassby 1995) and Kimmerer (Kimmerer 1998).

Actions to increase Delta outflow would be taken during the critical period, that is, before the critical period had ended and, therefore, before the average Delta outflow during the critical period were known. Nevertheless, some estimate of the action's effect on the average flow during the critical period must be made. This is done by entering the 50 percent exceedance estimate for Delta outflow during the critical period, that is, the average Delta outflow expected for the entire critical period, based on weather conditions up to the time of the action.

The spreadsheets calculate the change in this estimate resulting from the action and uses the expected value and the changed value to estimate the initial and final abundance.

Longfin Smelt Abundance vs. Delta Outflow*

Conditions	Delta Outflow cfs	Number of Days in the Critical Period	Duration of Action days	50% Exceedance Estimate of Average Delta Outflow Jan-June cfs	Estimated Abundance	Increase in Estimated Abundance %	95% Confidence Limits for Pop'n Increase	Exports Foregone acre-feet
Initial	20,000	181	14	20,000	820	**1.7**	**0.8**	**110,880**
Final	24,000			20,309	834		**2.5**	

* Data do not indicate a direct relationship between export rate and abundance of longfin smelt. However, changes in Delta outflow caused by changes in export rate should be entered in this spreadsheet.

Starry Flounder Abundance vs. Delta Outflow*

Conditions	Delta Outflow cfs	Number of Days in the Critical Period	Duration of Action days	90% Exceedance Estimate of Average Delta Outflow Jan-June cfs	Estimated Abundance	Increase in Estimated Abundance %	95% Confidence Limits for Pop'n Increase	Exports Foregone acre-feet
Initial	20,000	122	14	20,000	238	**2.0**	**0.6**	**110,880**
Final	24,000			20,459	243		**3.4**	

* Data do not indicate a direct relationship between export rate and abundance of starry flounder. However, changes in Delta outflow caused by changes in export rate should be entered in this spreadsheet.

BASIS OF THE SPREADSHEETS

These spreadsheets are based on analyses by Newman (Newman 2001a, Newman 2001b) and data and analyses shown in Appendix B. The critical period is the same critical period in the original analysis by Jassby et al (Jassby 1995) and Kimmerer (Kimmerer 1998).

ASSUMPTIONS

1. **Abundance indices are proportional to population**. This is a fundamental assumption underlying the use of abundance indices to describe population trends.

2. **Average Delta outflow (or value of X2) over the entire critical period for each species is the appropriate variable to use**. This assumption was implicit in the analyses underlying the X2 standard. However, it is possible that these critical periods could be shortened as more data become available.

SPLITTAIL

DEVELOPMENT OF SPREADSHEETS TO ESTIMATE POPULATION LEVEL EFFECTS

Splittail was one of the original "X2 species." That is, there is a correlation between the average value of X2 in February through May and the abundance of one-year-old splittail and splittail of all ages. However, there is now general consensus (see summary of the results of the CALFED Science Program Splittail Workshop, January 29, 2001) that the relationship is between abundance and average Delta inflow in February through May. Inflow is correlated with Delta outflow, which, of course, determines X2. The relationship between abundance and X2 did not change after the introduction of the Asian clam (Newman 2001a), which is further evidence that splittail abundance relates to inflow, which is upstream of the Asian clam, rather than outflow.

Using Delta inflow rather than X2 (or Delta outflow) is important because export rate directly affects Delta outflow but not Delta inflow. Export rate can affect Delta inflow if reductions in export rate result in lower reservoir releases, and in that case, as noted in the footnote to the spreadsheets, such changes in inflow should be entered in the spreadsheet.

Therefore, the straight-line correlation between the logarithm of abundance and logarithm of Delta inflow was used to estimate splittail abundance.

The tables below are an example of the spreadsheets for splittail. The first table shows population changes for young-of-the-year splittail, the second table for all ages of splittail.

The spreadsheets each require data for Delta inflow before and during the protective action as well as the duration of the action in days. Also, the expected value of the average Delta inflow, without the action, for February through May is required for the same reasons discussed above for longfin smelt and starry flounder.

The tables below are examples of an action consisting of an increase in Delta inflow from 16,000 cfs to 20,000 cfs for 14 days during the period February through May.

Splittail Abundance (Young-of-the-Year) vs. Delta Inflow*

Conditions	Delta Inflow cfs	Duration of Action days	Number of Days in Critical Period Feb-May cfs	50% Exceedance Estimate of Average Delta Inflow Feb-May cfs	Estimated Abundance	Increase in Pop'n %	95% Confidence Limits for Pop'n Increase	Additional River Flow Required acre-feet
Initial	16,000	14	120	16,000	0.87	**3.3**	**5.3**	**110,880**
Final	20,000			16,467	0.90		**2.6**	

* Data do not indicate a direct relationship between export rate and abundance of splittail. However, changes in Delta inflow associated with changes in export rate should be entered in this spreadsheet.

Splittail Abundance (All Ages) vs. Delta Inflow*

Conditions	Delta Inflow cfs	Duration of Action days	Number of Days in Critical Period Feb-May cfs	50% Exceedance Estimate of Average Delta Inflow Feb-May cfs	Estimated Abundance	Increase in Pop'n %	95% Confidence Limits for Pop'n Increase	Additional River Flow Required acre-feet
Initial	16,000	14	120	16,000	5.9	**1.3**	**1.0**	**110,880**
Final	20,000			16,467	6.0		**1.6**	

* Data do not indicate a direct relationship between export rate and abundance of splittail. However, changes in Delta inflow associated with changes in export rate should be entered in this spreadsheet.

ASSUMPTIONS

1. **February through May is the correct period over which to average Delta inflow**. If some other, shorter period could be found that would include essentially all splittail spawning, then that period could be used. Its use might result in a lower estimate of additional Delta inflow required.

SAN JOAQUIN RIVER FALL RUN SMOLTS

DEVELOPMENT OF SPREADSHEETS TO ESTIMATE POPULATION LEVEL EFFECTS

We used data from release and recapture experiments using hatchery grown, coded wire tagged, fall run smolts. These data were obtained before the VAMP program began. These data suffered from poor controls on the variability of both export rate and river flow between the time the smolts were released and the time they were recaptured. However, at this time, they are the only available data upon which to base these estimates. So far, the VAMP experiments have produced counterintuitive data suggesting that survival increases as export rate increases.

In these experiments, two groups of coded wire tagged smolts were released, one at the upstream location of interest and a second at a downstream location, much nearer Chipps Island. The upstream location was typically Mossdale or nearby, about 60 miles upstream of Chipps Island. The downstream release point was typically Jersey Point, about 16 miles upstream of Chipps Island. Sampling for both groups was carried out at the same time at Chipps Island.

An estimate of survival was made for each release group. Then, the survival estimate for the upstream release (typically Mossdale or nearby) was divided by the estimate for the Jersey Point group. In this way, the effects of confounding variables were discounted because they presumably applied to both estimates of survival. Therefore, the resulting survival ratio was a more stable measure of actual survival.

To estimate survival from the vicinity of Mossdale to Chipps Island, survival from Jersey Point to Chipps Island was assumed to be 1.0, that is, no mortality between Jersey Point and Chipps Island.

The paired releases we selected were those representing actual future conditions, namely, a barrier at the head of Old River when river flows were below about 7,000 cfs and no barrier when flows were higher. Therefore, the following data were used:

> For San Joaquin River flow at Vernalis less than 7,000 cfs, Mossdale releases with barrier in, all Dos Reis releases, and all Stockton releases.
>
> For San Joaquin River flow at Vernalis greater than 7,000 cfs, Mossdale releases without barrier.

These data, and, in fact, VAMP data collected to date do not show any relationship between smolt survival and export rate at river flows below 7,000 cfs with a barrier at the head of Old River (now, the normal practice) and above 7,000 cfs without a barrier (also the normal practice). Export rate is included in the spreadsheet, but, consistent with the data, export rate has no effect on survival.

The table below is an example of the spreadsheet for San Joaquin River fall run smolts. The spreadsheet requires entries for San Joaquin River flow before and during the action. Export rate (total for the State's Banks Pumping Plant and the federal Tracy Pumping Plant) before and during the action can be entered to estimate water cost for export curtailments. However, consistent with the data, no population change is predicted for a change in export rate. The duration of the action is required along with an estimate of the percentage of smolts outmigrating during the time the action is occurring.

This table is example of an action consisting of an increase in San Joaquin River flow from 2,000 cfs to 4,000 cfs for 31 days (mid-April to mid-May).

San Joaquin Fall Run Salmon Smolt Survival
vs. San Joaquin River Flow and Export Rate

Condi-tions	San Joaquin River Flow cfs	Export Rate* cfs	Duration of Action days	Outmig-rants Affected % of Total	Survival through Delta	Increase in Pop'n %	95% Confi-dence Limits for Pop'n Increase	Addit-ional River Flow Required acre-feet	Exports Fore-gone acre-feet
Initial	2,000	1,500	31	80	0.125	**11.0**	**10.4**	**101,277**	**0**
Final	3,650	1,500			0.142		**11.1**		

*Data do not indicate an effect of export rate on outmigrating smolts under normal barrier operation, namely, with a barrier at Old River when river flows are less than 7,000 and with no barrier when flows are greater than 7,000.

ASSUMPTIONS

1. **Changes in survival through the Delta can be used to estimate percent changes in adult population levels**. The rationale is the same as that for Sacramento fall run salmon.

2. **Survival from Jersey Point to Chipps Island is 1.0 and does not vary with San Joaquin River flow**. Survival is probably lower than 1.0, but changing this value has no effect on the estimates. If survival from Jersey Point to Chipps Island increases with increasing river flow, the estimate of population increase could somewhat higher.

REFERENCES

DWR 2001, http://www.iep.water.ca.gov/dayflow/input.html

Greene 2000, Sheila Greene, Department of Water Resources, personal communication, 2000

Hanson 1994, Evaluation of Environmental Factors Affecting Juvenile Chinook Salmon Monitoring Results within the Sacramento River and Georgiana Slough: 1994 (low flow conditions) and 1996 (high flow conditions"), draft memorandum by Charles R. Hanson.

Hanson 1995, Evaluation of the Response of Juvenile Chinook Salmon to the Flow Split at the Confluence Between Georgiana Slough and the Sacramento River, draft memorandum by Charles R. Hanson, October 27, 1995.

Hieb 1988, California Department of Fish and Game, Remarks at the spring 1988 X2 Workshop at the Contra Cost Water District.

Hollibaugh 1991, Potamocorbula amurensis: Comparison of Clearance Rates and Assimilation Efficiencies for Phytoplankton and Bacterioplankton, Interagency Ecological Study Program, Technical Report 29, 1991

Hollibaugh 1996, Publication of San Francisco Bay: The Ecosystem, Newsletter of the Interagency Ecological Program for the Sacramento-San Joaquin Estuary, Summer 1996.

Jassby 1995, Isohaline Position as an Habitat Indicator for Estuarine Populations, Jassby, A.D., Kimmerer, W.J., Monismith, S.G., Armor, C., Cloern, J.E., Powell, T.M., Schubel, J.R., Vendlinski, T.J., 1995, Ecological Applications, 5:272-289

Johnson 2001, Lance Johnson, water broker, personal communication, 2001

Kimmerer 1998, A Summary of the Current State of the X2 Relationships, Kimmerer, W.J., Newsletter of the Interagency Ecological Program for the Sacramento-San Joaquin Estuary, Fall, 1998.

Miller 1999, Estuarine Species Abundance, X2, and Sacramento-San Joaquin Delta Exports, Miller, W.J., Mongan, T.R., Britton, Alison, Newsletter of the Interagency Ecological Program for the Sacramento-San Joaquin Estuary, Spring, 1999

Moyle 2001, Draft, Sacramento Splittail White Paper, Peter B. Moyle, Randall D. Baxter, Ted Sommer, Ted C. Foin, and Robert R. Abbott, for CALFED, January 2001

Newman 1997, Statistical Model for Survival of Chinook Salmon Smolts Outmigrating through the Lower Sacramento-San Joaquin System, Newman, K and Rice, J, 1997

Newman 2000, K. Newman, Estimating and modeling absolute survival rates for juvenile chinook salmon outmigrating through the lower Sacramento river using paired release data, October, 2000, for California Department of Water Resources

Newman 2001a, Fish species abundance in San Francisco Bay and X2 relationship: pre- and post-Asian clam introduction, K. Newman, unpublished manuscript, May, 2001

Newman 2001b, Ken Newman, University of Idaho, personal communication, 2001

Peterson 1996, Potamocorbula Amurensis Spatial Distribution Study, Interagency Ecological Study Program, Summer, 1996

Schubel 1993, Managing Freshwater Discharge to the San Francisco Bay-Delta Estuary: the Scientific Basis for an Estuarine Standard, Schubel, J.R., 1993, San Francisco Estuary Project, U.S. Environmental Protection Agency

APPENDIX A
CALCULATION SPREADSHEETS, KEY ASSUMPTIONS, AND THE EFFECT OF THESE ASSUMPTIONS

SACRAMENTO FALL RUN SALMON

To create these spreadsheets, use the functions listed below for unshaded cells.

Fall Run Salmon Smolt Survival
vs. Export Rate and Cross Channel Position

	A	B	C	D	E	F	G	H	I	J	K
1	Condi-tions	Sacra-mento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Dur-ation of Action days	Outmig-rants Affected % of Total	Sur-vival through Delta	Increase in Pop'n %	95% Confi-dence Limits for Pop'n Increase	Additional River Flow Required acre-feet	Exports Fore-gone acre-feet
2	Initial	16,000	8,000	0	14	15	0.61	**4.4**	see other tables	**0**	**110,880**
3	Final	16,000	4,000	0			0.79		see other tables		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

Functions to enter

Cell G2: =(EXP(-34.05+3.69*LN(B2)+0.000152*IF(B2<27000,75231-7405*LN(B2),707-47.8*LN(B2))-0.000219*C2-0.87*D2))/(1+(EXP(-34.05+3.69*LN(B2)+0.000152*IF(B2<27000,75231-7405*LN(B2),707-47.8*LN(B2))-0.000219*C2-0.87*D2)))

Cell G3: =(EXP(-34.05+3.69*LN(B3)+0.000152*IF(B3<27000,75231-7405*LN(B3),707-47.8*LN(B3))-0.000219*C3-0.87*D3))/(1+(EXP(-34.05+3.69*LN(B3)+0.000152*IF(B3<27000,75231-7405*LN(B3),707-47.8*LN(B3))-0.000219*C3-0.87*D3)))

Cell H2:H3: =((G3-G2)/G2)*F2

Cell J2:J3: =(B3-B2)*1.98*E2

Cell K2:K3: =-(C3-C2)*1.98*E2

Fall Run Salmon Smolt Survival
vs. Export Rate but Not Cross Channel Position

	A	B	C	D	E	F	G	H	I	J	K
1	Condi-tions	Sacra-mento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Dur-ation of Action days	Outmig-rants Affected % of Total	Sur-vival through Delta	Increase in Pop'n %	95% Confi-dence Limits for Pop'n Increase	Additional River Flow Required acre-feet	Exports Fore-gone acre-feet
2	Initial	16,000	8,000	0	14	15	0.34	**11.6**	see other tables	**0**	**110,880**
3	Final	16,000	4,000	0			0.59		see other tables		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

Functions to enter

Cell G2: =(EXP(-32.6+3.47*LN(B2)+0.000128*IF(B2<27000,75231-7405*LN(B2),707-47.8*LN(B2))-0.000266*C2-0*D2))/(1+(EXP(-32.6+3.47*LN(B2)+0.000128*IF(B2<27000,75231-7405*LN(B2),707-47.8*LN(B2))-0.000266*C2-0*D2)))

Cell G3: =(EXP(-32.6+3.47*LN(B3)+0.000128*IF(B3<27000,75231-7405*LN(B3),707-47.8*LN(B3))-0.000266*C3-0*D3))/(1+(EXP(-32.6+3.47*LN(B3)+0.000128*IF(B3<27000,75231-7405*LN(B3),707-47.8*LN(B3))-0.000266*C3-0*D3)))

Cell H2:H3: =((G3-G2)/G2)*F2

Cell J2:J3: =(B3-B2)*1.98*E2

Cell K2:K3: =-(C3-C2)*1.98*E2

Fall Run Salmon Smolt Survival
vs. Cross Channel Position but Not Export Rate

	A	B	C	D	E	F	G	H	I	J	K
1	Condi-tions	Sacra-mento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Dur-ation of Action days	Outmig-rants Affected % of Total	Sur-vival through Delta	Increase in Pop'n %	95% Confi-dence Limits for Pop'n Increase	Additional River Flow Required acre-feet	Exports Fore-gone acre-feet
2	Initial	16,000	8,000	0	14	15	0.73	**0.0**	see other tables	**0**	**110,880**
3	Final	16,000	4,000	0			0.73		see other tables		

*If Sacramento River flow > 25,000 cfs, the Cross Channel gate position must be set to "Closed."

Functions to enter

Cell G2: =(EXP(-27.3+2.88*LN(B2)+0.000117*IF(B2<27000,75231-7405*LN(B2),707-47.8*LN(B2))-0*C2-1.02*D2))/(1+(EXP(-27.3+2.88*LN(B2)+0.000117*IF(B2<27000,75231-7405*LN(B2),707-47.8*LN(B2))-0*C2-1.02*D2)))

Cell G3: =(EXP(-27.3+2.88*LN(B3)+0.000117*IF(B3<27000,75231-7405*LN(B3),707-47.8*LN(B3))-0*C3-1.02*D3))/(1+(EXP(-27.3+2.88*LN(B3)+0.000117*IF(B3<27000,75231-7405*LN(B3),707-47.8*LN(B3))-0*C3-1.02*D3)))

Cell H2:H3: =((G3-G2)/G2)*F2

Cell J2:J3: =(B3-B2)*1.98*E2

Cell K2:K3: =-(C3-C2)*1.98*E2

Key assumptions, how to change them, and their effect on estimates of population change

1. **The number of adult salmon from these smolts is proportional to the number of smolts surviving passage through the Delta.** To change this assumption in the above spreadsheet, insert a multiplier to the terms in the cells for "Survival through Delta." So long as this multiplier is the same for both initial and final conditions, the estimated population change will not be affected.

2. **Conditions are the some as for the experiments that produced the data analyzed by Newman.** Note that the estimates produced by these spreadsheets are "expected" values, that is, those that would occur on the average. If conditions of interest are worse or better than average, in terms of smolt survival, then the calculated values in cells G2 and G3 should be adjusted by applying a factor to increase or decrease the value. So long as this factor is the same for both initial and final conditions, the estimated population change will not be affected.

3. **The fraction of total fall run outmigrants passing through the Delta during the action period can be estimated.** Different reasonable values for this fraction could be inserted in cell F2:F3 to see the effect of this assumption. The effect of such is change is directly proportional to the estimate of the fraction of smolts affected by the action.

4. **The amount of water required could not be made up at some other time.** To reflect this possibility, a factor reflecting the likelihood of make-up occurring could be added to the cell under "Additional River Flow Required" or the cell under "Exports Foregone." For example, if there was thought to be a 30 percent chance of making up exports foregone, the entry in cell K3 could be multiplied by the factor (1-0.3).

LATE FALL, WINTER, AND SPRING RUN SALMON

To create this spreadsheet, use the functions listed below for unshaded cells.

	A	B	C	D	E	F	G	H	I
1	Conditions	Sacra-mento River Flow* cfs	Export Rate cfs	Cross Channel Gate 1=Open 0=Closed	Fraction of Smolts Entering DCC & Geor. Sl./Fraction of Water Entering	Survival from Ryde to Chipps	Overall Survival Sacra-mento to Chipps Island	Duration of Action days	Estimated Outmig-rants Affected % of Total
2	Initial	16,000	8,000	0	0.58	0.8	0.74	14	15
3	Final	16,000	4,000	0			0.75		

	J	K	L	M	O	P
1	Increase in Population %	95% Confidence Limits for Population Increase %	Additional River Flow Required acre-feet	Exports Foregone acre-feet	Survival Lower 95%	Survival Upper 95%
2	**0.2**	**0.22**	**0**	**110,880**	0.68	0.79
3		**0.53**			0.71	0.77

Functions to enter

Cell G2: =IF(D2=0,(F2*(1+E2*(0.133+829/B2)*(0.521-(0.000034*C2)-1))),(F2*(1+E2*(0.293+2090/B2)*(0.521-(0.000034*C2)-1))))

Cell G3: =IF(D3=0,(F2*(1+E2*(0.133+829/B3)*(0.521-(0.000034*C3)-1))),(F2*(1+E2*(0.293+2090/B3)*(0.521-(0.000034*C3)-1))))

Cell J2:J3: =(I2/100)*((G3-G2)/G2)*100

Cell K2: =ABS((I2/100)*((O3-O2)/O2)*100)

Cell K3: =(I2/100)*((N3-N2)/N2)*100

Cell L2:L3: =(B3-B2)*1.98*H2

Cell M2:M3: =-(C3-C2)*1.98*H2

Cell O2: =IF(E3=0,(G3*(1+F3*(0.133+829/C3)*(0.215-(0.0000702*D3)-1))),(G3*(1+F3*(0.293+2090/C3)*(0.215-(0.0000702*D3)-1))))

Cell O3: =IF(E4=0,(G3*(1+F3*(0.133+829/C4)*(0.215-(0.0000702*D4)-1))),(G3*(1+F3*(0.293+2090/C4)*(0.215-(0.0000702*D4)-1))))

Cell P2: =IF(E3=0,(G3*(1+F3*(0.133+829/C3)*(0.823+(0.00000226*D3)-1))),(G3*(1+F3*(0.293+2090/C3)*(0.823-(0.00000226*D3)-1))))

Cell P3: =IF(E4=0,(G3*(1+F3*(0.133+829/C4)*(0.709-(0.000000147*D4)-1))),(G3*(1+F3*(0.293+2090/C4)*(0.709-(0.000000147*D4)-1))))

Key assumptions, how to change them, and their effect on estimates of population change

1. **The number of adult salmon produced from these smolts is proportional to the number of smolts surviving passage through the Delta.** To change this assumption in the above spreadsheet, insert a multiplier to the terms in the cells for "Overall Survival Sacramento to Chipps Island." So long as this multiplier is the same for both initial and final conditions, the estimated population change will not be affected.

2. **Actions whose population effects are being estimated are occurring within the range of conditions under which the original data were collected.** Note that the estimates produced by these spreadsheets are "expected" values, that is, those that would occur on the average. If conditions of interest are worse or better than average, in terms of smolt survival, then the calculated values in cells G2 and G3 should be adjusted by applying a factor to increase or decrease the value. So long as this factor is the same for both initial and final conditions, the estimated population change will not be affected.

3. **The fraction of total fall run outmigrants passing through the Delta during the action period can be estimated.** Different reasonable values for this fraction could be inserted in cell I2:I3 to see the effect of this assumption. The effect on population increase of changing this factor is proportional to the change; the increase in population is 0.2 percent if 10 percent of the smolts are affected and 0.8 percent if 50 percent of them are affected.

4. **The amount of water required could not be made up at some other time**. To reflect this possibility, a factor reflecting the likelihood of make-up occurring could be added to the cell under "Additional River Flow Required" or the cell under "Exports Foregone." For example, if there was thought to be a 30 percent chance of making up exports foregone, the entry in cell M3 could be multiplied by the factor (1-0.3).

5. **Survival from Ryde to Chipps Island is 0.8**, a generally accepted value (Greene 2000). This survival estimate can be changed or made a function of one or more factors such as temperature and salinity. So long as the survival from Ryde to Chipps Island is the same for both the initial and final conditions, there is essentially no effect on the increase in population.

6. **The fraction of Sacramento River flow entering Georgiana Slough or the Cross Channel (if open) can be estimated from the equations used in Dayflow**, the Department of Water Resources method of accounting for Delta flow (DWR 2001).

7. **The ratio of the fraction of smolts entering Georgiana Slough and the Cross Channel is 0.58 of the fraction of water entering either of those channels.** (Hanson 1994, Hanson 1995) The increase in population varies from 0.7 percent if this factor is 0.5, up to 6.5 percent if this factor is 3.0 (For example, if 30 percent of the water enters the side channels, 90 percent of the smolts do.). The variation in the increase in population is roughly linear with the increase in this factor.

8. **No smolts that pass the City of Sacramento enter Steamboat or Sutter Sloughs.** This is an environmentally conservative assumption because smolts entering these two sloughs are not affected by export rate.

9. **That the smolt survival experiments can also be used to estimate survival of outmigrating winter run salmon** (Pat Brandes, US Fish and Wildlife Service).

LONGFIN SMELT AND STARRY FLOUNDER

To create these spreadsheets, use the functions listed below for unshaded cells.

Longfin Smelt

	A	B	C	D	E	F	G	H
1	Conditions	Delta Outflow cfs	Duration of Action days	Number of Days in Critical Period, Jan-June	50% Exceedance Estimate of Average Delta Outflow Jan-June cfs	Estimated Abundance	Increase in Estimated Abundance %	95% Confidence Limits for Increase in Abundance
2	Initial	10,000	14	181	12,000	475	**2.8**	**1.4**
3	Final	14,000			12,309	488		**4.2**

	I	J	K
1	Additional Delta Outflow Required acre-feet	Estimated Abundance Lower 95%	Estimated Abundance Upper 95%
2	**110,880**	0.0147	15,215,569
3		0.0149	15,849,698

Functions to enter

Cell E3: =E2+(C2/D2)*(B3-B2)

Cell F2: =EXP(-3.9+1.0713*LN(E2))

Cell F3: =EXP(-3.9+1.0713*LN(E3))

Cell G2:G3: =100*((F3-F2)/F2)

Cell H2: =100*((J3-J2)/J2)

Cell H3: =100*((K3-K2)/K2)

Cell I2:I3: =(B3-B2)*1.98*C2

Cell J2: =EXP(-9.27+0.538*LN(E2))

Cell J3: =EXP(-9.27+0.538*LN(E3))

Cell K2: =EXP(1.472+1.604*LN(E2))

Cell K3: =EXP(1.472+1.604*LN(E3))

Starry Flounder

	A	B	C	D	E	F	G	H
1	Conditions	Delta Outflow cfs	Dur-ation of Action days	Number of Days in Critical Period, Jan-June	50% Exceedance Estimate of Average Delta Outflow Jan-June cfs	Estimated Abundance	Increase in Estimated Abundance %	95% Confidence Limits for Increase in Abundance
2	Initial	10,000	14	122	12,000	153	**3.3**	**0.9**
3	Final	14,000			12,459	158		**5.8**

	I	J	K
1	Additional Delta Outflow Required acre-feet	Estimated Abundance Lower 95%	Estimated Abundance Upper 95%
2	**110,880**	0.00093	25,138,268
3		0.00093	26,584,952

Functions to enter

Cell E3: =E2+(C2/D2)*(B3-B2)

Cell F2: =EXP(-3.145+0.8701*LN(E2))

Cell F3: =EXP(-3.145+0.8701*LN(E3))

Cell G2:G3: =100*((F3-F2)/F2)

Cell H2: =100*((J3-J2)/J2)

Cell H3: =100*((K3-K2)/K2)

Cell I2:I3: =(B3-B2)*1.98*C2

Cell J2: =EXP(-9.329+0.2495*LN(E2))

Cell J3: =EXP(-9.329+0.2495*LN(E3))

Cell K2: =EXP(3.0392+1.4906*LN(E2))

Cell K3: =EXP(3.0392+1.4906*LN(E3))

Key assumptions, how to change them, and their effect on estimates of population change

1. **Abundance indices are proportional to population**. There is no basis on which this assumption might be changed.

2. **Average Delta outflow (or value of X2) over the entire critical period for each species is the appropriate variable to use**. This assumption was implicit in the analyses underlying the X2 standard. However, it is possible that these critical periods could be shortened as more data become available. If this occurred, the correlation analyses could be redone and new relationships used in the spreadsheets.

SPLITTAIL

To create these spreadsheets, use the functions listed below for unshaded cells.

Splittail Young-of-the-Year*

	A	B	C	D	E	F	G	H
1	Conditions	Delta Inflow cfs	Duration of Action days	Number of Days in Critical Period, Feb-May	50% Exceedance Estimate of Average Delta Inflow Feb-May cfs	Estimated Abundance %	Increase in Estimated Abundance %	95% Confidence Limits for Increase in Estimated Abundance
2	Initial	16,000	14	120	16,000	0.87	**3.3**	**5.3**
3	Final	20,000			16,467	0.90		**2.6**

	I	J	K
1	Additional Delta Inflow Required acre-feet	Upper 95% Confidence Limits for Increase in Estimated Abundance	Lower 95% Confidence Limits for Increase in Estimated Abundance
2	**110,880**	3.20	-0.170
3		3.28	-0.161

* Data do not indicate a direct relationship between export rate and abundance of splittail. However, changes in Delta inflow associated with changes in export rate should be entered in this spreadsheet.

Functions to enter

Cell E3: =E2+(C2/D2)*(B3-B2)

Cell F2: =(10^(0.04781+0.00001397*E2))-1

Cell F3: =(10^(0.04781+0.00001397*E3))-1

G2:G3: =100*((F3-F2)/F2)

Cell H2: =ABS(100*((K3-K2)/K2))

Cell H3: =100*((J3-J2)/J2)

Cell I2:I3: =(B3-B2)*1.98*C2

Cell J2: =(10^(0.336+0.00001797*E2))-1

Cell J3: =(10^(0.336+0.00001797*E3))-1

Cell K2: =(10^(-0.2404+0.000009972*E2))-1

Cell K3: =(10^(-0.2404+0.000009972*E3))-1

Splittail All Ages*

	A	B	C	D	E	F	G	H
1	Conditions	Delta Inflow cfs	Duration of Action days	Number of Days in Critical Period, Feb-May	50% Exceedance Estimate of Average Delta Inflow Feb-May cfs	Estimated Abundance %	Increase in Estimated Abundance %	95% Confidence Limits for Increase in Estimated Abundance
2	Initial	16,000	14	120	16,000	5.9	**1.3**	**1.0**
3	Final	20,000			16,467	6.0		**1.6**

	I	J	K
1	Additional Delta Inflow Required acre-feet	Upper 95% Confidence Limits for Increase in Estimated Abundance	Lower 95% Confidence Limits for Increase in Estimated Abundance
2	**110,880**	12.55	2.5
3		12.75	2.6

* Data do not indicate a direct relationship between export rate and abundance of splittail. However, changes in Delta inflow associated with changes in export rate should be entered in this spreadsheet.

Functions to enter

Cell E3: =E2+(C2/D2)*(B3-B2)

Cell F2: =(10^(0.6771+0.0000102*E2))-1

Cell F3: =(10^(0.6771+0.0000102*E3))-1

Cell G2:G3: =100*((F3-F2)/F2)

Cell H2: =100*((K3-K2)/K2)

Cell H3: =100*((J3-J2)/J2)

Cell I2:I3: =(B3-B2)*1.98*C2

Cell J2: =(10^(0.9118+0.00001375*E2))-1

Cell J3: =(10^(0.9118+0.00001375*E3))-1

Cell K2: =(10^(0.4424+0.00000665*E2))-1

Cell K3: =(10^(0.4424+0.00000665*E3))-1

Key assumptions, how to change them, and their effect on estimates of population change

1. **February through May is the correct period over which to average Delta inflow**. If some other, shorter period could be found that would include essentially all splittail spawning, then that period could be used. Its use might result in a lower estimate of additional Delta inflow required.

SAN JOAQUIN RIVER FALL RUN SALMON

To create these spreadsheets, use the functions listed below for unshaded cells.

	A	B	C	D	E	F	G	H
1	Conditions	San Joaquin River Flow cfs	Export Rate* cfs	Duration of Action days	Estimated Outmigrants Affected % of Total	Estimated Survival through Delta	Increase in Population %	95% Confidence Limits for Population Increase
2	Initial	2,000	1,500	31	80	0.125	**13.3**	**12.6**
3	Final	4,000	1,500			0.146		**13.5**

	I	J	K	L
1	Additional River Flow Required acre-feet	Exports Foregone acre-feet	Estimated Survival Lower 95% Confidence Limits	Estimated Survival Upper 95% Confidence Limits
2	**122,760**	**0**	0.07	0.18
3			0.08	0.22

Functions to enter

Cell F2: =0.1044+0.00001039*B2

Cell F3: =0.1044+0.00001039*B3

Cell G2:G3: =((F3-F2)/F2)*E2

Cell H2: =((K3-K2)/K2)*E2

Cell H3: =((L3-L2)/L2)*E2

Cell I2:I3: =(B3-B2)*1.98*D2

Cell J2:J3: =-(C3-C2)*1.98*D2

Cell K2: =0.0551+0.00000516*B2

Cell K3: =0.0551+0.00000516*B3

Cell L2: =0.1537+0.00001561*B2

Cell L3: =0.1537+0.00001561*B3

ASSUMPTIONS

1. **Changes in survival through the Delta can be used to estimate percent changes in adult population levels**. The rationale is the same as that for Sacramento fall run salmon.

2. **Survival from Jersey Point to Chipps Island is 1.0 and does not vary with San Joaquin River flow**. Survival is probably lower than 1.0, but changing this value has no effect on the estimates. If survival from Jersey Point to Chipps Island increases with increasing river flow, the estimate of population increase could somewhat higher.

APPENDIX B
DATA AND ANALYSES

SACRAMENTO FALL RUN SALMON

Data and analyses are presented in the report by Newman (Newman 2001a).

LATE FALL, SPRING, AND WINTER RUN SALMON

Total Export Rate cfs	Sacramento River Flow cfs	Ratio of Survivals S_{Geor}/S_{Ryde}
10,682	21,517	0.15
7,075	19,133	0.28
11,763	62,900	0.15
10,755	32,439	0.26
10,977	24,161	0.04
4,721	69,961	0.28
2,040	54,827	0.24
2,318	20,287	0.72

SUMMARY OF LINEAR REGRESSION OF RATIO OF SURVIVALS AGAINST EXPORT RATE				
R Square =	0.4673241			
	Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.5211375	0.0058875	0.215239243	0.827035811
Export Coef.	-3.4E-05	0.0615785	-7.0188E-05	2.25901E-06

SUMMARY OF LINEAR REGRESSION OF RATIO OF SURVIVALS AGAINST RIVER FLOW				
R Square =	0.031136	R Square too low		
	Coefficients	*P-value*		
Intercept	0.308771	0.0602758		
Export Coef.	-1.4E-06	0.6759539	Not statistically significant	

Best Fit					
S_{Geor}/S_{Ryde} = 0.521-0.000034*Exports					
Lower 95%					
S_{Geor}/S_{Ryde} = 0.215-0.0000702*Exports					
Upper 95%					
S_{Geor}/S_{Ryde} = 0.823 +0.00000226*Exports					

LONGFIN SMELT AND STARRY FLOUNDER

	Starry Flounder Age 1		Longfin Smelt	
	Delta Outflow Average cfs Mar-Jun	Abundance Index	Delta Outflow Average cfs Jan-Jun	Abundance Index
1967			69,415	81,790
1968			20,353	3,300
1969			83,696	60,059
1970			54,540	6,535
1971			33,920	15,987
1972			12,545	760
1973			48,362	5,897
1975			34,953	2,819
1976			6,003	658
1977			2,745	210
1978			45,121	6,675
1980	16,501	691	54,342	31,155
1981	38,400	1,434	11,385	2,202
1982	10,312	293	76,023	62,549
1983	74,339	4,017	129,887	11,875
1984	134,585	1,440	33,345	7,459
1985	16,431	291	9,471	992
1986	6,861	477	60,737	6,160
1987	56,125	395	8,922	1,520
1988	8,062	128	6,617	791
1989	5,319	73	10,826	456
1990	14,243	66	4,573	243
1991	4,276	107	6,658	134
1992	7,700	138	8,462	76
1993	5,901	1	40,035	798
1994	35,419	69	9,797	545
1995	7,434	177	86,926	8,646
1996	95,760	281	53,745	1,388
1997	44,700	489	67,597	690
1998	15,706	776	99,934	6,654
1999	81,320	539	44,416	5,242
2000	34,546	156	36,822	3,438

	Starry Flounder Age 1		Longfin Smelt	
	Log Delta Outflow Mar-Jun	Log Abun-dance Index	Log Delta Outflow Jan-Jun	Log Abun-dance Index
1967			11.148	11.312
1968			9.921	8.102
1969			11.335	11.003
1970			10.907	8.785
1971			10.432	9.680
1972			9.437	6.633
1973			10.786	8.682
1975			10.462	7.944
1976			8.700	6.489
1977			7.918	5.347
1978			10.717	8.806
1980	9.711	6.538	10.903	10.347
1981	10.556	7.268	9.340	7.697
1982	9.241	5.680	11.239	11.044
1983	11.216	8.298	11.774	9.382
1984	11.810	7.272	10.415	8.917
1985	9.707	5.673	9.156	6.900
1986	8.834	6.168	11.014	8.726
1987	10.935	5.979	9.096	7.326
1988	8.995	4.852	8.797	6.673
1989	8.579	4.290	9.290	6.122
1990	9.564	4.190	8.428	5.493
1991	8.361	4.673	8.804	4.898
1992	8.949	4.927	9.043	4.331
1993	8.683	0.000	10.598	6.682
1994	10.475	4.234	9.190	6.301
1995	8.914	5.176	11.373	9.065
1996	11.470	5.638	10.892	7.236
1997	10.708	6.192	11.121	6.537
1998	9.662	6.654	11.512	8.803
1999	11.306	6.290	10.701	8.564
2000	10.450	5.050	10.514	8.143

Starry Flounder Age 1 Statistical Analysis, all years' data					
	R Square =	0.31			
		Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
	Intercept	-3.1448265	0.300491723	-9.3288239	3.039170807
Log Outflow Coeff.		0.87007946	0.008506094	0.249515632	1.490643295

Longfin Smelt Statistical Analysis, post-1987 data					
	R Square =	0.64			
		Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
	Intercept	-3.9004342	0.138359938	-9.27281941	1.471950962
Log Outflow Coeff.		1.07132064	0.001023915	0.538171388	1.604469886

SPLITTAIL

YEAR	Delta Inflow Feb-May Average cfs	Abundance Index Young-of-the-Year	Log(Abun+1)
1980	72,859	3.4	0.643
1981	23,325	2.7	0.568
1982	100,218	109	2.041
1983	168,622	75	1.881
1984	33,199	0.7	0.230
1985	18,040	0	0.000
1986	110,622	45	1.663
1987	18,543	0.7	0.230
1988	15,107	1.2	0.342
1989	25,509	0	0.000
1990	14,860	1.8	0.447
1991	15,204	15	1.204
1992	18,069	1.2	0.342
1993	52,448	6	0.845
1994	15,160	0	0.000
1995	120,695	75	1.881
1996	80,364	11.2	1.086
1997	48,527	1.1	0.322
1998	121,536	239.1	2.380
1999	60,869	6.4	0.869
2000	64,021	4.8	0.763

Splittail Young-of-the-Year Statistical Analysis					
	R Square =	0.74			
		Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
	Intercept	0.04781252	0.732202224	-0.24035367	0.335978706
Delta Inflow Coeff.		1.3973E-05	6.23323E-07	9.97218E-06	1.79743E-05

YEAR	Delta Inflow Feb-May Average cfs	Abundance Index All Ages	Log(Abun+1)
1967	73,895	65	1.820
1968	31,487	18	1.279
1969	98,584	28	1.462
1970	50,044	25	1.415
1971	37,138	18	1.279
1972	20,141	13	1.146
1973	55,274	4	0.699
1975	52,369	4	0.699
1976	14,464	1	0.301
1977	7,532	0	0.000
1978	65,632	37	1.580
1980	72,859	16	1.230
1981	23,325	18	1.279
1982	100,218	118	2.076
1983	168,622	152	2.185
1984	33,199	16	1.230
1985	18,040	15	1.204
1986	110,622	58	1.771
1987	18,543	29	1.477
1988	15,107	9	1.000
1989	25,509	4	0.699
1990	14,860	8	0.954
1991	15,204	18	1.279
1992	18,069	4	0.699
1993	52,448	11	1.064
1994	15,160	3	0.643
1995	120,695	76	1.889
1996	80,364	22	1.360
1997	48,527	1	0.322
1998	121,536	282	2.451
1999	60,869	39	1.607
2000	64,021	8	0.954

Splittail All Ages Statistical Analysis					
	R Square =	0.53			
		Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
	Intercept	0.6770994	1.88544E-06	0.44241147	0.91178733
Delta Inflow Coeff.		1.0201E-05	2.02503E-06	6.65E-06	1.3752E-05

SAN JOAQUIN RIVER FALL RUN

Release Location	Release Date	Ratio of Survivals, Release Location/ Jersey Point	Old River Barrier	Median San Joaquin River Flow cfs	Median Delta Exports cfs
Dos Reis	4/21/93	0.162	no	2,240	10,020
Dos Reis	4/17/94	0.063	no	1,300	5,657
Dos Reis	5/3/94	0.034	no	1,293	2,248
Dos Reis	4/16/95	0.092	no	907	4,686
Dos Reis	4/18/99	0.320	no	18,600	3,706
Dos Reis	5/2/00	0.070	no	6,635	1,601
Dos Reis	5/2/00	0.117	no	6,496	1,551
Dos Reis	4/18/02	0.314	**no**	22,383	1,830
Dos Reis	4/25/02	0.270	**no**	18,250	1,908
Dos Reis	4/30/01	0.181	yes	5,965	2,282
Dos Reis	4/30/01	0.301	yes	5,965	2,282
Dos Reis	5/9/01	0.281	yes	5,770	2,291
Mossdale	4/27/98	0.133	yes	2,560	1,533
Mossdale	4/29/01	0.183	yes	5,938	2,280
Stockton	5/6/91	0.141	no	1,082	4,409
Stockton	5/11/91	0.112	no	835	3,138

San Joaquin River Fall Run Statistical Analysis, River Flow and Export Rate				
	R Square =	0.57		
		Coefficients	*P-value*	
	Intercept	0.08964308	0.044202378	
River Flow Coeff.		1.0774E-05	0.00134262	
	Export Coeff.	3.7763E-06	**0.658787871**	**not significant**

San Joaquin River Fall Run Statistical Analysis					
	R Square =	0.56			
		Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
	Intercept	0.10435133	0.000462623	0.055051407	0.153651252
River Flow Coeff.		1.0387E-05	0.000788978	5.16025E-06	1.56133E-05

APPENDIX C
LOCATION MAP
THE DELTA