Review of Analyses Presented at the Environmental Water Account Meeting
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Summary

- B. Herbold *et al*. did a graphical analysis of salvage numbers at the Banks and Tracy pumping facilities. This showed that the winter (November to March) salvage rates of threadfin shad, striped bass, delta smelt and longfin shad have tended to increase since about 2000, and that these increases are apparently not accounted for by changes in the amount of water pumped or changes in the fish population numbers. A similar increase in salvage is also observed for inland silversides and centrarchids. They discuss possible causes for the increased salvage (changes at the salvage facilities, increased susceptibility of fish to salvage, environmental changes, and hydrological influences on the distribution of the fish or their food). They note, however, the need for more research in all of these areas. The graphs of B. Herbold *et al*. were found to be correct. Randomization tests indicates that the observed changes in mean winter salvage between 1994-99 and 2000-05 are very unlikely to have occurred by chance. Similarly, the observed changes in winter salvage densities (the salvage values per volume of water exported) and the observed changes in the salvage densities divided by Fall Midwater Trawl (FMWT) abundance indices are quite unlikely to have occurred by chance. These randomization tests confirm that salvage rates have increased in recent years for the fish considered, and that these increases are not accounted for by changes in pumping rates or changes in pumping rates combined with changes in the abundance of fish.

- B. Herbold *et al*. discuss the possibility that it is hydrodynamic influences that are responsible for increased salvage. They note that the DSM-2 particle tracking model shows that at export to inflow ratios greater than 20% almost all particles released close to the export facilities are entrained, while for releases further away the percentage entrained increases linearly with the export to inflow (E/I) ratio. The implication therefore is that it is increased E/I ratios that are responsible for the increased salvage. However, no attempt was made to relate the observed salvage to these ratios. The idea that increased winter salvage is related in a simple linear way to increases in the E/I ratio in recent years is not supported by the data on a monthly or daily basis. Instead the relationship between salvage and the Export/Inflow ratio at the monthly and daily levels suggests that very high ratios are associated with low salvage rates. On a daily basis the highest salvage levels have been observed with E/I ratios of about 20%. However, at these levels of E/I there is also a great deal of variation in the salvage rates. It would be interesting to try to relate this variation to other factors, concentrating on data from times when the E/I ratio is close to 20%. The factors involved might not be the same as those responsible for the low salvage at low and high E/I ratios.

- M. Guerin *et al*. describe an analysis designed to find an equation to predict the Summer Townet (STN) juvenile delta smelt abundance index. They considered a large number of possible regression equations, with variables either log-transformed or not. As a result of these analyses they concluded that one equation is of particular interest.

This relates the STN index to the water salinity at Jersey Point in the fall (October-December) and to the FMWT sub-adult delta smelt abundance index prior to the STN index. Guerin *et al*. also tried adding winter exports into the equation but say that this did not give a significant improvement to the equation. The regression equation that was fitted by Guerin *et al*. relating the STN abundance index to salinity at Jersey Point and the FMWT abundance index is correct. It accounts for about 72% of the variation in the data and is not significantly improved by adding winter (November to March) export rates as an explanatory variable. There is some indication that the residuals from the model may be related to winter export rates, and that the salinity at Jersey Point may be positively related to winter export rates, but these apparent effects are not statistically significant.

- T. Swanson first considered the relationship between the STN juvenile delta smelt abundance index and the following FMWT sub-adult abundance index, and also the relationship between the FMWT index and the following STN index. Very highly significant relationships were found. The regression results for log(STN) against Log(FMWT) described by T. Swanson are correct. There is clear evidence of a positive relationship between the two indices in the same water year. There are, however, apparent patterns in the regression residuals which suggest that these may be correlated, the patterns are related to the values of a missing covariate, or the equation changed over the period being considered. The residuals have been negative since 2000, with the residual for 2005 being the most extreme ever observed. When a regression with correlated errors is considered it accounts for slightly more of the variation in the data than the ordinary regression, at the expense of estimating one more parameter. It does not eliminate the pattern in residuals. The results of the regression of Log(FMWT) values against the previous Log(STN) values given by Swanson are also correct. This equation also has some apparent patterns in the residuals. A slightly better fit to the observed data can be obtained using a regression with correlated errors, but this still does not account for the low Log(FMWT) values in 2004 and 2005, and the estimated correlation structure involving Log(FMWT) being related to the regression residual two years before is hard to account for.

- In further analyses T. Swanson considered the relationship between exports and the delta smelt abundance indices. Her analyses suggest winter exports have a negative effect on sub-adult delta smelt abundance as measured by the FMWT index, and that spring and summer exports have a negative effect on juvenile abundance, as measured by the STN index. However, the apparent relationship between Log(STN) values and the prior winter exports over the period 1969 to 2005 seems questionable. There are patterns in the regression residuals that indicate correlation in these residuals, a missing covariate, or change with time in the mean of the Log(STN) values. If correlated residuals are allowed for then the estimated effect of winter exports is small and not statistically significant. If the mean of Log(STN) is assumed to change between 1982 and 1983 then the estimated change is highly significant and this model for the data accounts for far more variation than any of the other models considered.

Given the change in the mean of Log(STN) between 1983 and 1983 there is no evidence that Log(STN) values are related to winter exports. Nevertheless, systematic patterns in the residuals suggest that Log(STN) may be determined to some extent by some unmeasured covariate.

- The regression of Log(FMWT) values against the winter export rate is highly significant, but there are patterns in the residuals. If these patterns are modeled assuming correlated regression residuals then the correlation in regression residuals is found to be significant and the estimated regression accounts for 36.4% of the variation in the data. There is no longer a significant effect of winter exports, but still some patterns in the regression residuals. Also, the model assumes that Log(FMWT) values are related to regression residuals two years before, which is hard to account for. Another possibility is to assume that the mean of Log(FMWT) changed at some point between 1967 and 2005, in which case the most obvious change point is between 1982 and 1983. Assuming a change in the mean of Log(FMWT) at that point accounts for 26.6% of the variation in Log(FMWT) values. The estimated effect of winter exports is then approaching significance assuming that it was constant over the full period 1967 to 2005. There are still patterns in the residuals for the model assuming a change in the mean of Log(FMWT) between 1982 and 1983. If these are modeled assuming correlated regression residuals then 40.5% of the variation in Log(FMWT) values can be accounted for without any estimated winter export effects. There is, however, still an assumed relationship between Log(FMWT) values and the regression residuals two years before that is hard to account for. Therefore a model with a change in the mean between 1982 and 1983 without correlated residuals may be preferred. None of the models considered account for the very low FMWT values in 2004 and 2005.

- The final analysis considered by T. Swanson related Log(STN) to the total exports from March to July in total acre-feet in the same year as the STN abundance index was estimated for. A simple regression of Log(STN) values against total exports from March to July is clearly significant but it under-estimates the Log(STN) values up to the early 1980s and then over-estimates the values. There is an apparent shift in the mean of Log(STN) between 1982 and 1983. Allowing for a change in the mean, the effect of total exports is no longer quite significant. When the observed and expected values of Log(STN) are plotted against years it is apparent that there are still patterns in the residuals, suggesting that there is a variable affecting the results that is not in the model. Also, the model does not account for the very low Log(STN) value in 2005.

- Five analyses made by B.J. Miller are reviewed. The first of these provides estimates of adult delta smelt abundances in January, February and March, based on Kodiak trawl sampling, which has been carried out since 2002. The estimated abundances obtained by Miller (2005a) are found to be correct. Given various uncertainties associated with the assumptions behind these estimates they should be regarded as

initial approximations which may be modified when more information about these assumptions becomes available.

- The second analysis of B.J. Miller related the FMWT delta smelt sub-adult abundance index to a measure of the overlap between delta smelt and their prey in July. There is a very highly significant relationship between the FMWT index and the Miller *et al*. (2005) overlap index calculated using either the sum of the *E. affinis* and *P. forbesi* densities, or the *P. forbesi* density alone. A less significant result is obtained if the overlap index is calculated using the densities of *E. affinis*, *P. forbesi*, *A. sinensis* and *T. species*, because this hides the effect of *P. forbesi* to some extent.

- The third analysis of B.J. Miller involved relating the estimated total adult delta smelt salvage at the state and federal export facilities to the estimated number of adult delta smelt east of Franks Tract from the Spring Kodiak Trawl, and other variables. There are some differences between the data used here and that used by B.J. Miller, and in one case the regression equation calculated here is quite different from the one given by B.J. Miller. Nevertheless, the estimated abundance of adult delta smelt east of Franks Tract from Spring Kodiak Trawl sampling is a good predictor of the total salvage at the state and federal export facilities, and once the effects of this variable are allowed for, other variables are not clearly related to salvage.

- The fourth analysis carried out by B.J. Miller was done to estimate the numbers of delta smelt adults that were entrained at the state and federal pumping facilities as a percentage of the adult population in February, for the years 1994 to 2005. The estimation of the number of adult delta smelt entrained at the pumping facilities is in principle quite simple, but is based on several assumptions. The estimated numbers of delta smelt entrained are reasonable, given the assumptions. To calculate the estimated percentages of adult delta smelt entrained requires dividing the estimated numbers entrained by an estimate of the population size of delta smelt. Here the February Kodiak Trawl estimated abundances were used for this purpose for 2002 to 2005, excluding the abundances in the Sacramento Ship Channel for the years when this area was sampled. As the Kodiak Trawl was not designed to provide a population estimate of delta smelt, the Kodiak Trawl abundances should be regarded as approximations to the true abundances. On this basis the estimated percentages entrained can be regarded as the best guess at the true percentages, except that they should possibly be reduced by about 25% because the Kodiak Trawl abundance estimates do not include the Sacramento Ship Channel. For the years 1994 to 2001 the Kodiak Trawl abundances had to be estimated using the previous FMWT abundance index. This adds an extra element of uncertainty to the estimated percentages entrained, although they can still be thought of as best guesses for the true percentages. The estimated percentages entrained are generally quite low (5% or less), although in 2003 the estimated percentages are higher, ranging from 10.8% to 18.2%, depending on the assumptions made.

- The fifth analysis carried out by B.J. Miller examined the relationship between various measures of adult delta smelt salvage and the subsequent FMWT sub-adult delta smelt abundance index. These relationships were examined again here, but with some corrections to the data. No evidence was found for a relationship between the FMWT abundance index and (i) the percentage entrained at the pumping stations, (ii) the adult salvage divided by the February Kodiak Trawl delta smelt abundance estimate, (iii) the adult salvage divided by the FMWT abundance index in the year before, (iv) the adult salvage divided by the export rate from November to March, (v) the adult salvage and the export rate from November to April, (vi) adult salvage, and (vii) adult salvage and the FMWT abundance index from the previous year. The percentage change in the FMWT abundance index from one year to the next was also not significantly related to the adult salvage divided by the FMWT abundance index in the earlier year.

- A table is provided summarizing the conclusions from all of the analyses that have been reviewed.

1. Introduction

At the Environmental Water Account (EWA) workshop held in Sacramento December 7-8, 2005, a number of statistical analyses were described that relate either directly or indirectly to the effects of water exports from the Sacramento-San Joaquin Delta on delta smelt abundance in the delta. As the results of some of these analyses appeared to indicate the existence of an export effect while other analyses did not, it was agreed that I should obtain the data used for all of the analyses, recreate the analyses, and comment both on the methods used and the validity of the conclusions reached.

To facilitate this process, a meeting was held at the University of California Davis campus on January 5, 2006, at which the proponents of the various analyses described the source of their data, details about the analyses, and the assumptions made. The purpose of this meeting was not to reach any conclusions about the validity or otherwise of particular analyses. Instead it was intended to enable everyone present to better understand the methods of analysis used, and, in particular, to assist me to exactly recreate the analyses used.

Following the January 5 meeting, Sheila Greene (California Department of Water Resources, Sacramento) produced a list of the analyses to be considered in my review, including questions and issues that were not resolved at the meeting. The following sections of this report are in the order of that list, except when it was convenient to change the order for various reasons.

Abbreviations used throughout this report are defined in Appendix A. Appendix B lists the data sources used. Appendix C contains the larger tables involved in the various analyses.

All significance tests considered in this report are two-sided, even though in some cases many people would be prepared to specify the direction of an effect should it exist. With highly significant results the difference between a one-sided and a two-sided test is not important. However, in some cases there is significance at the 5% level with a one-sided test, but not with a two-sided test. This should be taken into account when considering the results presented here. Also, results are stated to be significant when the significance level is 5% or less, although in some cases many people would consider a less stringent level when deciding about the evidence for the possible existence of an effect of interest. Standard errors are given for estimated effects to indicate the precision of those estimates.

This report generally only considers the analyses discussed during the January 5, 2006, meeting. These analyses were either presented at the EWA workshop in December 2005, or are related to analyses that were presented at that workshop. Analyses conducted by other researchers are not considered here, although they may provide useful additional information about the issues of interest.

A clear conclusion from the analyses that are considered in this report is that more work is needed to understand the factors that affect the abundance of delta smelt and other fish in the Sacramento-San Joaquin Delta. In particular it is concluded that the recent large decline in abundance of delta smelt and other pelagic fish does not seem to be accounted for by any of the factors considered.

2. Analyses Made by B. Herbold

Graphical Analysis for Delta Smelt

Herbold *et al*. (2006) did a mainly graphical analysis of salvage rates at the Banks and Tracy pumping facilities. This showed that the winter (November to March) salvage rates of threadfin shad, striped bass, delta smelt, and longfin shad have tended to increase since about 2000, and that these increases are apparently not accounted for by changes in the amount of water pumped or changes in the fish population numbers. A similar increase in salvage is also observed for inland silversides and centrarchids. Herbold *et al*. discuss possible causes for the increased salvage (changes at the salvage facilities, increased susceptibility of fish to salvage, environmental changes, and hydrological influences on the distribution of the fish or their food). They note, however, the need for more research in all of these areas.

Graphs for Delta Smelt

The data used by Herbold *et al*. (2006) was provided by B. Herbold in the file Salvage_Data_Jan_93_-_Sept_05_-_4.xls on January 9, 2006. I checked the delta smelt salvage data against the results in B.J. Miller's file Smelt_Salvage_Length.xls. Apart from the discrepancies noted in Appendix B the values agreed. I did not check the source of the data for the total amount of water exported each winter in acre-feet. However, I did compare these data with the export rates (cfs) in the file Adult_Entrainment.xls provided by B.J. Miller, and there was a more or less perfect ratio relationship. Therefore the data from these two sources agree. The FMWT abundance values are as provided at the web site www.delta.dfg.ca.gov/data/mwt/charts.asp. I did not check the salvage values for the species other than delta smelt. Table 2.1 shows the data used here.

Table 2.1 Winter (November-March) exports, salvage numbers, and Fall Midwater Trawl abundance indices for water years 1994 to 2005.

	Winter	Estimated Winter Salvage						FMWT Abundance Indices			
Water Year	Exports (af)	Striped Bass	Treadfin Shad	Longfin Smelt	Delta Smelt	Silver-sides	Centrar-chids	Striped Bass	Treadfin Shad	Longfin Smelt	Delta Smelt
1994	1972783	152299	277822	68	447	9694	63637	1557	6679	798	1078
1995	2192119	434657	292153	78	2608	29496	68461	1259	2305	545	102
1996	1812428	42780	315662	108	5634	5367	22240	484	3337	8646	899
1997	1771388	172084	603906	12	1840	9177	111223	392	4758	1388	127
1998	1954445	223325	1470178	126	1027	21315	40844	568	15268	690	303
1999	1379529	28923	213894	26	2074	5747	9003	1224	5748	6654	420
2000	2750683	125614	472639	129	11517	10527	32589	541	7527	5242	864
2001	2477253	439054	1589631	237	8301	24662	22994	390	12977	3438	756
2002	2638958	352747	2351457	1029	6865	25644	55174	731	14402	247	603
2003	2719017	234414	4625951	297	14323	51094	124957	71	1753	707	139
2004	2949547	230838	3839711	324	8148	37518	128090	108	1956	191	210
2005	2615536	160714	3035483	30	2000	52333	144529	53	1301	190	74

Figure 2.1 shows the salvage rates from Table 2.1 plotted against the water year, where, for example, water year 1994 is October 1993 to September 1994. The vertical scale is logarithmic in order that trends can be seen for all six fish types. For all fish there is some suggestion that salvage increased after 1999, but this is most apparent for threadfin shad, inland silversides, delta smelt and longfin smelt.

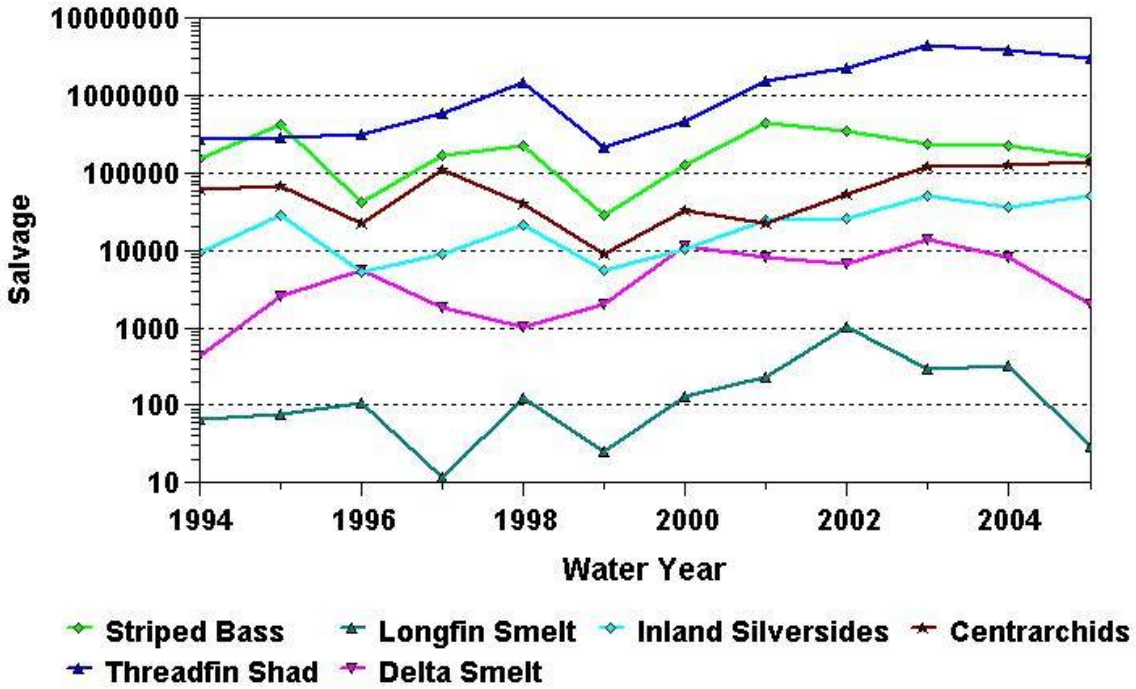

Figure 2.1 The estimated winter salvage counts (with a logarithmic scale) for six fish for the water years 1994 to 2005.

The significance of the apparent changes shown in Figure 2.1 can be assessed using randomization tests (Manly, 1997). For example, the difference between the mean salvage 2000-05 and the mean salvage 1994-99 can be compared with the distribution of the differences that is obtained by repeatedly putting the salvage values in a random order. The null hypothesis is then that the salvage rates are in a random order with respect to time. If the observed mean difference has a very small probability of occurring based on this null hypothesis then there is evidence against it, so that there is evidence of some pattern in the data.

I carried out randomization tests using Resampling Stats for Excel (Blank, 2005), using 50,000 randomizations. The following results were obtained, where the difference shown is the difference between the mean salvage for 2000-05 and the mean salvage for 1994-99, and the p-value is the probability of obtaining such a large difference by chance if the salvage numbers are effectively in a random order:

Fish	Difference	P-value
Striped Bass	81552	0.309
Threadfin Shad	2123543	0.008
Longfin Smelt	271	0.022
Delta Smelt	6254	0.009
Inland Silversides	20164	0.031
Centrarchids	32154	0.256

The observed difference is highly significant for threadfin shad and delta smelt, and significant at the 5% level for longfin smelt and inland silversides. It can be noted that all of the observed differences are positive, even when they are not significant.

Assuming that the different fish provide independent data, Fisher's (1970) method can be used to assess the overall evidence for changes between 1994-99 and 2000-05. This method is based on the fact that if n independent tests are carried out and all of the null hypotheses are true, then

$$S = -2 \sum \log_e(p_i)$$

follows a chi-squared distribution with 2n df, where p_i is the p-value from the ith test, and the summation is over the results for the n tests. From the results given above, n = 6 and S = 38.67. In comparison with the chi-squared distribution with 12 df the probability of a value of S this large by chance is 0.0001. Consequently, there is overwhelming evidence overall of at least some changes.

Figure 2.2 shows values for the winter salvage density (the salvage per 100 TAF of exports for the fish being considered). If salvage has been mainly determined by the amount of water pumped then these values should be fairly constant. There is, however, a suggestion of higher values after 1999 for threadfin shad, delta smelt and longfin smelt.

Randomization tests can again be run to test whether the mean salvage density 2000-05 is significantly different from the mean density for 1994-1999. Again 50,000 randomizations were used, giving the following results:

Fish	Difference	P-value
Striped Bass	850	0.794
Threadfin Shad	69530	0.023
Longfin Smelt	9	0.051
Delta Smelt	189	0.040
Inland Silversides	557	0.110
Centrarchids	345	0.755

All of the differences are again positive, with three of them being significant at the 5% level. Fisher's method for combining the test results gives S = 25.36. Comparing this with the chi-squared distribution with 12 df shows that the probability of an S value this large by chance is 0.013. There is evidence for at least some changes in the salvage densities, although this is not as strong as the evidence for changes in salvage numbers.

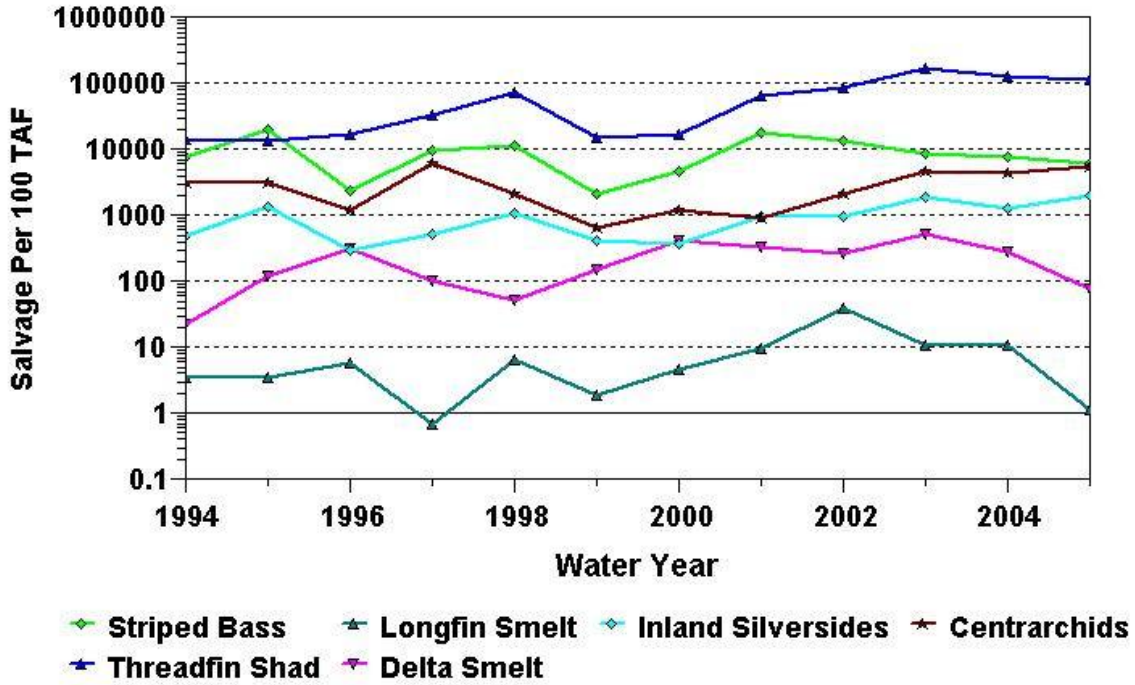

Figure 2.2 The winter salvage for six fish per volume of water exported for the water years 1994 to 2005.

Figure 2.3 shows values for the salvage per 100 TAF divided by the previous FMWT abundance index for striped bass, longfin smelt, threadfin shad and delta smelt. These values are assumed to allow for changes in the amount of water pumped and the abundance of the fish being considered. Therefore the values should be fairly constant if the salvage for a fish is determined by the amount of water pumped and the abundance of the fish. In fact, an apparent increase with time is apparent for all four fish.

Randomization tests were again used to see if the 2000-05 mean is significantly different from the 1994-99 mean. As before, 50,000 randomizations were used. The results are as follows:

Fish	Difference	P-value
Striped Bass	51.634	0.024
Threadfin Shad	39.721	0.099
Longfin Smelt	0.036	0.107
Delta Smelt	0.769	0.162

All the differences are again positive, but the only result that is significant at the 5% level is for striped bass. Nevertheless, the p-values are all fairly small and Fisher's method for combining test results gives S = 20.20. Comparing this with the chi-squared distribution with 8 df shows that it is significant at the 1% level. Hence overall there is evidence of changes in the mean from 1994-99 to 2000-05. It seems, therefore, that the salvage increase after 1999 is not accounted for by changes in the amount of water pumped and changes in fish abundance.

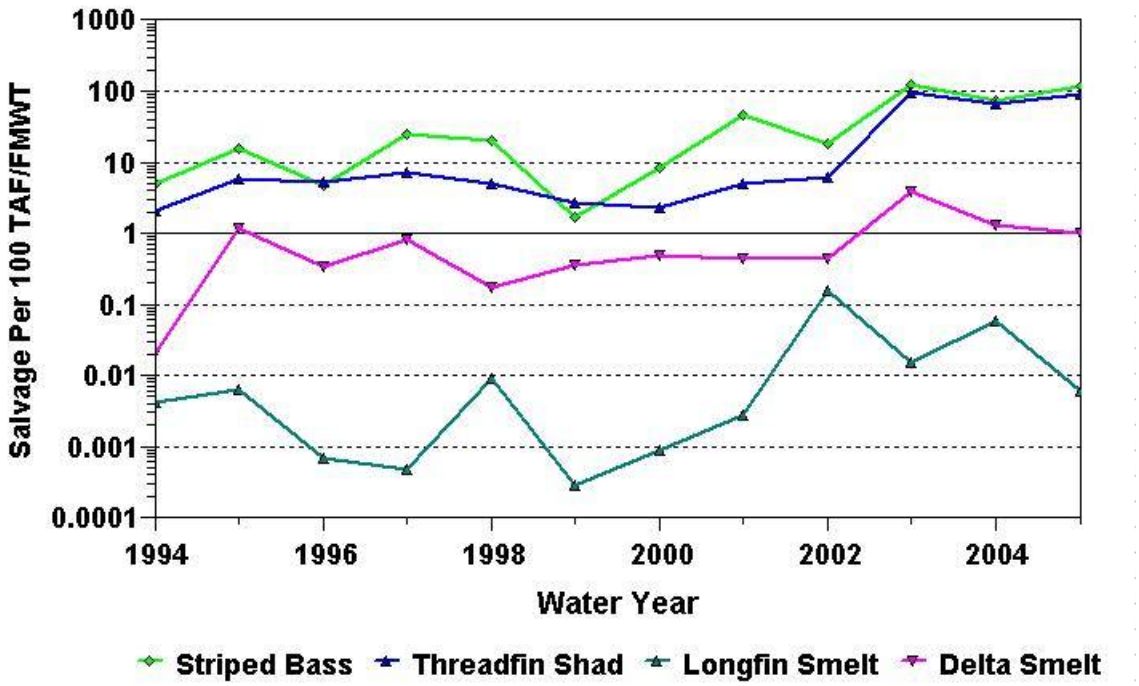

Figure 2.3 The winter salvage for four fish per volume of water exported, divided by the previous FMWT abundance index for the water years 1994 to 2005.

Conclusions

Figures 1 to 6 of Herbold *et al*. (2006) are correct. Randomization tests indicates that the changes in the mean estimated winter salvage values between 1994-99 and 2000-05 are extremely unlikely to have occurred by chance. Similarly, changes in the winter salvage densities (the salvage values per volume of water exported) and changes in the

winter salvage densities divided by the previous FMWT abundance indices are quite unlikely to have occurred by chance, although these changes are not significant for all fish. It seems, therefore, that there has been a general increase in the salvage of the fish considered since 1999, and this increase is not accounted for by changes in the amount of water pumped, or changes in the amount of water pumped combined with changes in the abundance of fish.

2a. Extra Analyses Relating Export to Inflow Ratios

Herbold *et al*. (2006) discuss the possibility that it is hydrodynamic influences that are responsible for increased salvage. They note that the DSM-2 particle tracking model shows that at export to inflow ratios greater than 20% almost all particles released close to the export facilities are entrained, while for releases further away the percentage entrained increases linearly with the export to inflow (E/I) ratio. In Table 3 of Herbold *et al*. (2006) the E/I ratios are shown for November to March of 1994 to 2005. It is noted that the average ratio 1994-2000 was 24% while the average 2001-2005 was 36%. The implication therefore is that it is increased E/I ratios that are responsible for the increased salvage. However, no attempt was made to relate the observed salvage to these ratios.

Analysis of Monthly Salvage and the E/I Ratio

If it is increased E/I ratios that are responsible for increased salvage then this should show up in a comparison of monthly salvage rates against monthly E/I ratios, using the data in Table 3 of Herbold *et al*. (2006) and the winter monthly salvage rates in Salvage_Data_Jan_93_-_Sept_05_-_4.xls. Table C1 shows the data. It is apparent from this table that if salvage increases are related to increases in the E/I ratio then this is not on a monthly basis. For each water year the month with the highest salvage is in bold. This is never the month with the largest E/I ratio, and often the E/I ratio is relatively low. Furthermore, the months with high E/I ratios often have quite low salvage.

A plot of adult monthly salvage rates against the corresponding monthly E/I ratios is provided in Figure 2.4. This figure shows that the highest salvage has not occurred with the highest E/I ratios. The plot indicates which points are for water years 1994-99 and which points are for 2000-05. The salvage levels clearly tend to be higher in the later period but are still low with the highest E/I ratios. The pattern shown is that salvage is low for very low and very high E/I ratios, while with moderate E/I ratios there is a great deal of variation in the salvage levels.

I analyzed the monthly adult salvage data using log-linear models, with an allowance for over-dispersion. Almost all salvage is of adults, so I did not consider juvenile salvage. The first factor input to account for adult salvage was the water year. That accounted for a nearly significant amount of the variation in the data ($F = 1.83$ with 11 and 48 df, $p = 0.075$). I then added in a month of the year effect and got a very highly significant improvement in fit ($F = 9.97$ with 4 and 44 df, $p < 0.001$). I then added the E/I ratio and got

a significant improvement in fit (F = 5.27 with 1 and 43 df, p = 0.027). Finally I added in the E/I ratio squared and got a very significant improvement in fit (F = 8.54 with 1 and 42 df, p = 0.006).

I also considered the possibility that the relationship between salvage and the E/I ratio change after the water year 1999. I did this by allowing the coefficients of E/I and E/I squared to be different for the two periods 1994-99 and 2000-05. This did not give a significant improvement in fit (F=2.54 with 2 and 40 df, p = 0.091). Therefore there is no clear evidence that the relationship changed.

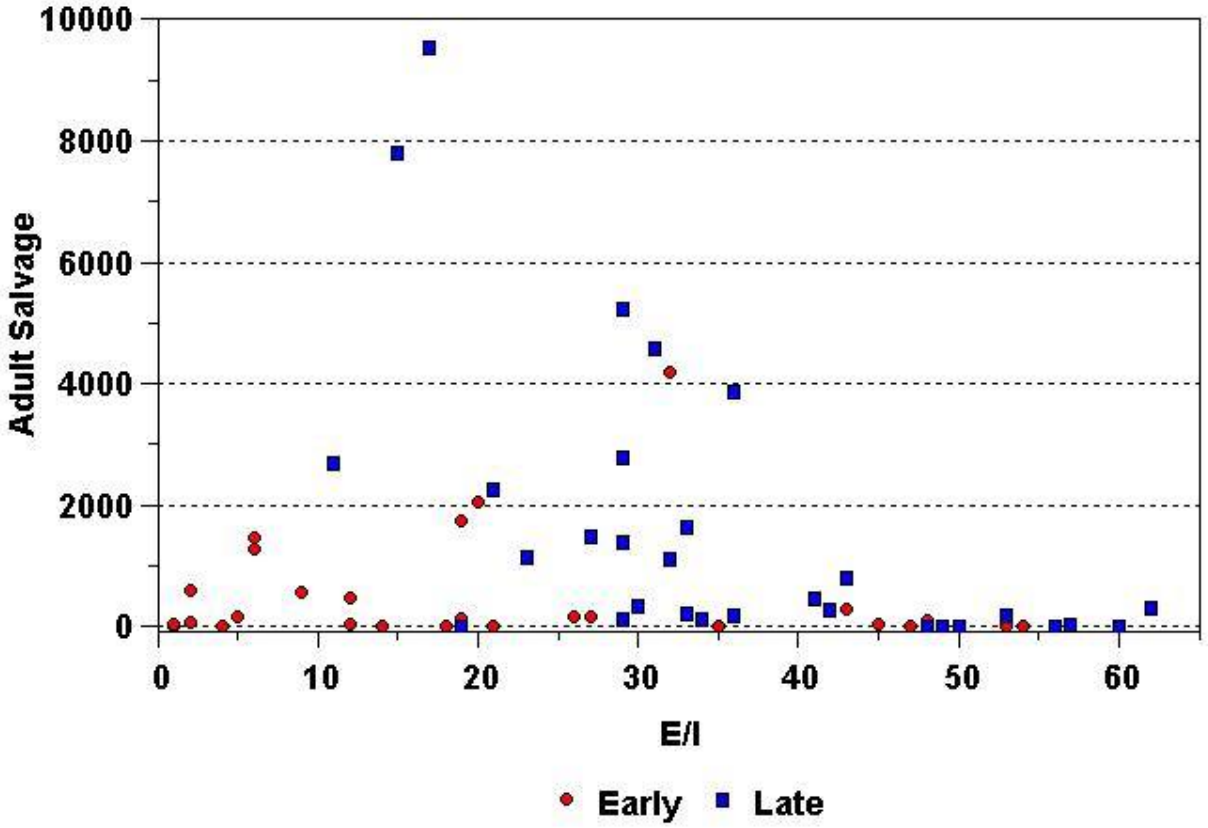

Figure 2.4 Adult salvage rates plotted against the Export/Inflow ratio for winter months (November-March), 1993-2005. Early are values for water years 1994-99, Late are for water years 2000-05.

It is important to realize that the relationships between salvage and the E/I ratio being considered here are based on variation within years, after allowing for the total salvage to vary from year to year, and allowing for some months to tend to have more salvage than others. The estimated functions are therefore not affected by the recent increases in the total yearly salvage.

Based on the log-linear models the estimated relationships between the expected salvage and the E/I ratio are shown in Figure 2.5. Three curves are shown. One is estimated using the data from all water years, one is estimated just using data from the

early water years (1994-99), and the other one is estimated just using the data from the later water years (2000-04). To make the curves comparable, they have all been scaled to a value of 100 with a 20% E/I ratio. The curve based on all the data suggests that maximum salvage tends to occur with the 20% E/I ratio. The curve based on the early data suggests that the maximum tends to occur at a higher E/I ratio of about 30%. The curve based on the late data suggests that maximum salvage tends to occur with very low E/I ratios. However, as there were no very low E/I ratios in the late period, this is a gross extrapolation from the data, which only really suggest that salvage declines as the E/I ratio increases from about 15% (Figure 2.4).

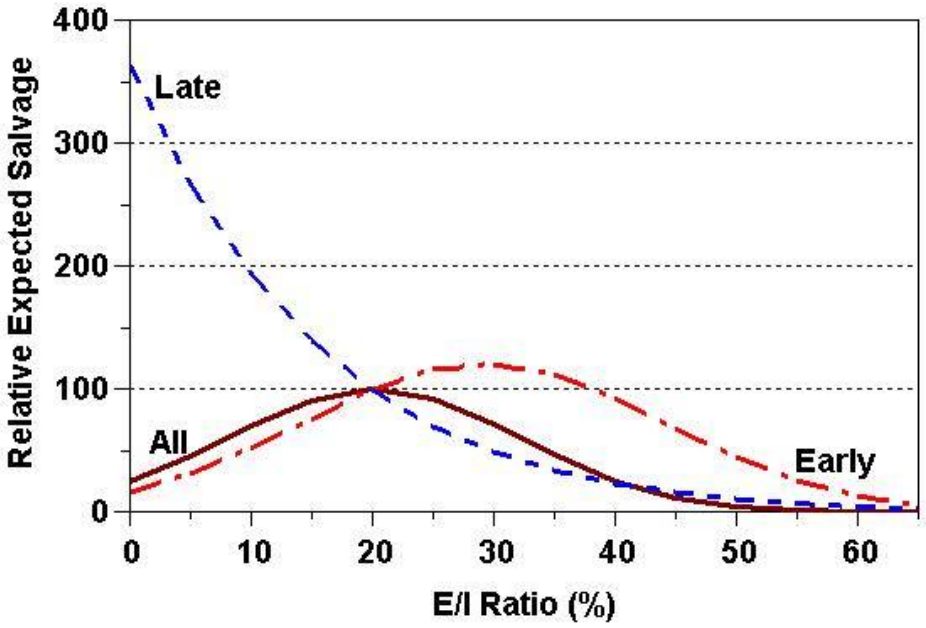

Figure 2.5 The estimated relationship between salvage and the Export/Inflow ratio for January 1994. The Early curve is based on data for water years 1994-1999 and late curve is based on data for water years 2000-2005. The All curve is estimated using all of the data.

Finally, it turns out that the patterns shown in Figure 2.4 also hold when daily salvage rates are related to daily E/I ratios (Figure 2.6). In this case the highest salvage occurred with daily E/I ratios of about 20%, both in the early and late period, with reduced levels for higher and lower E/I ratios. For E/I ratios of about 20% the salvage is not necessarily high. It varies over the full range from zero to the highest observed levels.

Conclusions

The idea that increased winter salvage is related in a simple linear way to increases in the Export/Inflow ratio in recent years is not supported by the data on a monthly or daily basis. Indeed the relationship between salvage and the Export/Inflow ratio at the monthly and daily levels suggests that very high ratios are associated with very low salvage rates.

It seems likely that the truth of the matter is that the high salvage in recent years is not just a result of increases in the E/I ratio, because other factors such as the distribution of delta smelt are involved. These other factors might, for example, be indirectly responsible for the coincidence that when the Export/Inflow ratio has been very high the salvage has tended to be very low.

Figure 2.6 shows that on a daily basis the highest salvage levels have been observed with E/I ratios of about 20%. However, at these levels of E/I there is also a great deal of variation in the salvage rates. It would be interesting to try to relate this variation to other factors, concentrating on data from times when the E/I ratio is close to 20%. The factors involved might not be the same as those responsible for the low salvage at low and high E/I ratios. The low salvage rates at low E/I ratios is presumably due to a relatively small amount of water passing through the pumps. The reason for the low salvage rates at high E/I ratios is not clear.

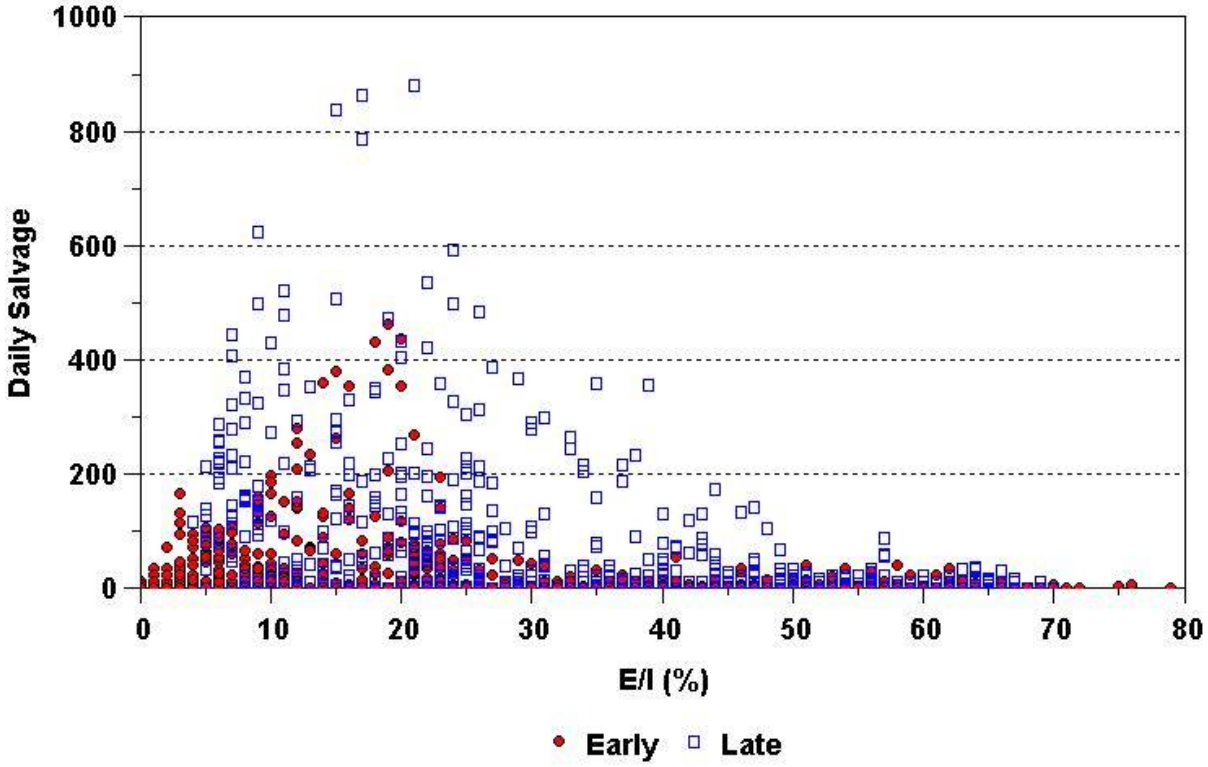

Figure 2.6 Daily salvage numbers plotted against daily Export/Inflow (E/I) ratios for January 1993 to March 2004. The early points are for water years 1994-99 and the late points are for water years 2000-05.

3. Analyses Made by Guerin *et al*

Guerin *et al*. (2006) describe an analysis designed to find an equation to predict the delta smelt STN abundance index. They apparently considered a large number of possible regression equations, with variables either log-transformed or not. As a result of these analyses they concluded that one equation is of particular interest. This relates the STN index to the water salinity at Jersey Point in the fall (October-December) and to the FMWT abundance index prior to the STN index. Guerin *et al*. also tried adding winter exports into the equation but say that this did not give a significant improvement to the equation.

Regression Analysis

The data for the Guerin *et al*. regression equation are provided in two Excel files. The file JP_EC_IEP_HECDSS_Avg_FallAvg_to_Greene_Manly.xls contains monthly salinity data at Jersey Point. The file Regressjpecfmwtvsfolyrstn_1987_to_Greene_Manly.xls contains the regression calculations. Both files were provided by M. Guerin and are dated January 9, 2006. These files do not contain the data for winter exports. Monthly export rates are, however available in the file Monthly_Exports_57-05.xls provided by B.J. Miller and dated January 12, 2006.

Table 3.1 shows the data obtained from these various files. I checked the values for the FMWT and STN abundance indices against those at the www.delta.dfg.ca.gov website. The values are correct. I checked the average fall salinity values at Jersey Point by averaging the monthly values in JP_EC_IEP_HECDSS_Avg_FallAvg_to_Greene _Manly.xls. The fall averages are correct. I did not check the accuracy of the monthly salinity values themselves. I calculated the winter (November to March) average export rates from the monthly values in the file Monthly_Exports_57-05.xls. I did not check whether the monthly values are correct.

Figure 3.1 shows a plot of the STN abundance index values against the other variables and the water year. There is an apparent negative relationship between STN and the salinity at Jersey Point (JPEC), an apparent positive relationship with the FMWT index, and an apparent negative relationship with the export rate.

Guerin *et al*. related the STN index to JPEC/1000 and FMWT/100. This gives the equation

$$STN = 7.7821 - 4.2835(JPEC/1000) + 0.5901(FMWT/100),$$

which accounts for 71.8% of the variation in STN. The estimated standard error of the coefficient of JPEC/1000 is 1.0330 so the coefficient is very highly significant ($t = -4.15$ with 15 df, $p = 0.001$). The estimated standard error of the coefficient of FMWT/100 is 0.1767 so this coefficient is also highly significant ($t = 3.34$ with 15 df, $p = 0.004$).

If Exports/1000 is added to the equation then the variation in STN accounted for increases to 74.8%. The estimated equation is

$$STN = 10.5396 - 3.7656(JPEC/1000) + 0.5734(FMWT/100) - 0.4442(Exports/1000).$$

The standard errors associated with the coefficients of JPEC/1000, FMWT/100 and Exports/1000 are 1.0865, 0.1733 and 0.3426, respectively. This gives t-values for the three statistics of -3.47, 3.31 and -1.30, respectively, each with 14 df, with significance levels of 0.004, 0.005 and 0.216, respectively. Hence the export effect is not significant at the 5% level.

Table 3.1 The EC salinity at Jersey point October to December (JPEC), the Fall Midwater Trawl abundance index (FMWT), the average export rate November to March (cfs), and the Summer Townet abundance index (STN), for water years 1988 to 2005.

Water Year	JPEC	FMWT	Exports	STN
1988[a]	1673.2	280	8535.0	1.2
1989	2101.1	174	8247.2	2.2
1990	1743.9	366	10377.6	2.2
1991	2184.7	364	5517.6	2.0
1992	1781.5	689	5746.0	2.6
1993	1213.9	156	6606.8	8.2
1994	942.0	1078	6602.4	13.0
1995	1159.9	102	7371.4	3.2
1996	238.4	899	5972.4	11.1
1997	571.2	127	5890.6	4.0
1998	1059.6	303	6486.0	3.3
1999	392.7	420	4629.6	11.9
2000	979.4	864	9159.0	8.0
2001	1578.1	756	8152.4	3.5
2002	1301.9	603	8813.6	4.7
2003	1408.0	139	9114.0	1.6
2004	1483.1	210	9834.2	2.9
2005	1310.1	74	8804.2	0.3

[a]Water year 1988 runs from October 1987 to September 1988, inclusive.

There are other regressions that can be considered as well. A regression of STN just on the export rate gives

$$STN = 13.1009 - 1.1035(Exports/1000).$$

The standard error of the coefficient of Exports/1000 is 0.5163 so that the coefficient is just significant at the 5% level ($t = -2.14$ with 16 df, $p = 0.048$). However, this equation only accounts for 22.2% of the variation in the data. Adding FMWT into the equation changes it to

$$STN = 8.4524 - 0.8807(Exports/1000) + 0.7024(FMWT/100),$$

which accounts for 53.2% of the variation in the data. The standard error of the coefficient of Exports/1000 is 0.4196, so that it is not quite significant at the 5% level ($t = -2.10$ with 15 df, $p = 0.053$. The standard error of the coefficient of FMWT/100 is 0.2229. This coefficient is therefore much more significant ($t = 3.15$ with 15 df, $p = 0.007$).

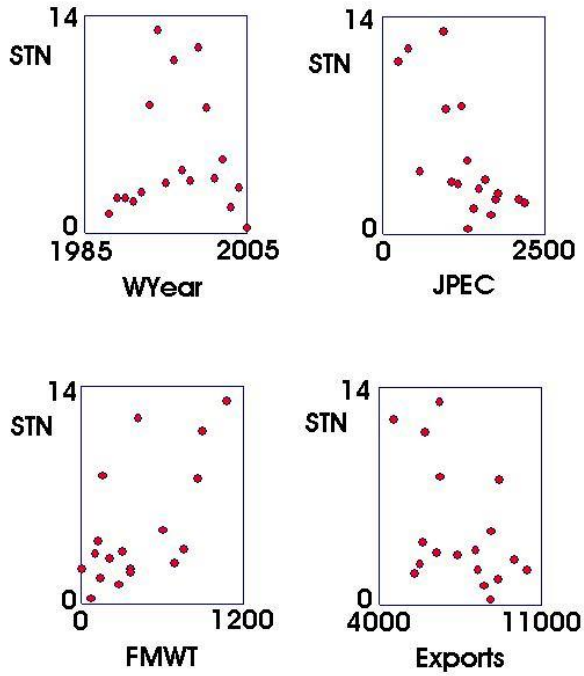

Figure 3.1 Values of the STN abundance cindex plotted against the water year (WYear), salinity (JPEC) and the average winter export rate (cfs).

In terms of accounting for the variation in STN, the equation involving JPEC and the FMWT index is clearly best, with 71.8% of the variation accounted for. Adding the export rate into this equation does increase the amount of variation accounted for to 74.8%. However, adding a variable into a regression equation cannot decrease the amount of variation accounted for, and in this case the extra amount accounted for by exports is not at all significant.

Figure 3.2 shows the standardized residuals from the regression of STN against JPEC and FMWT. These standardized residuals are the differences between the observed and expected values of STN from the regression equation, divided by the residual standard deviation. In general, most standardized residuals should be in the range from -2 to +2, and almost all in the range from -3 to +3. The standardized residuals shown in the figure are reasonable in this respect. However, there is a suggestion that the residuals tended to be high with low exports and low with high exports. This is not a significant effect because if it was then adding exports to the regression equation would give a significant

improvement in fit. Still, the suggestion of a pattern is there. If real, this pattern would imply that at low export rates the regression equation tends to under-estimate the STN index, while at high export rates the equation tends to over-estimate the STN index.

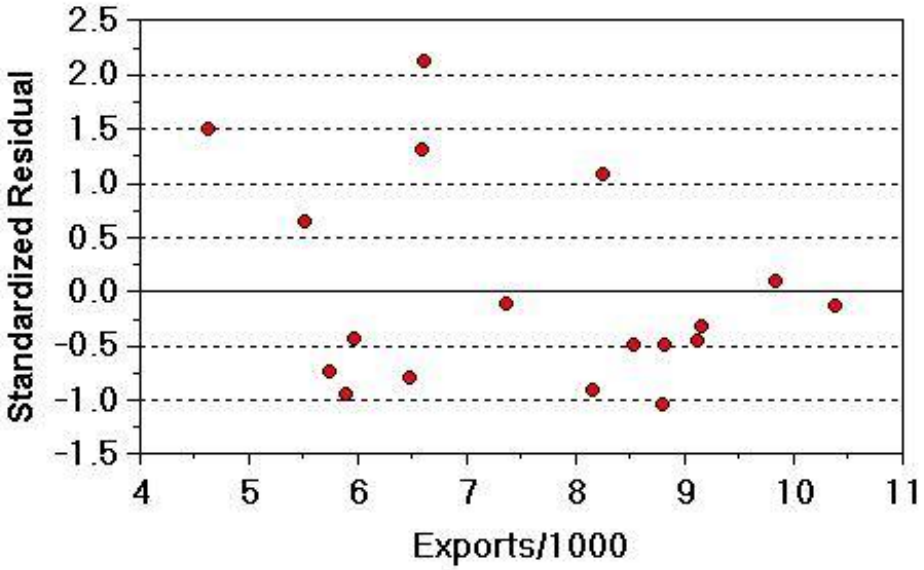

Figure 3.2 Standardized residuals from the regression of the STN abundance index against Jersey point salinity and the FMWT abundance index.

It is also interesting to plot the standardized residuals against the water year, as shown in Figure 3.3. This shows that from 1995 to 2005 there have been nine negative and two positive residuals. The equation has therefore tended to over-estimate the STN index in recent years.

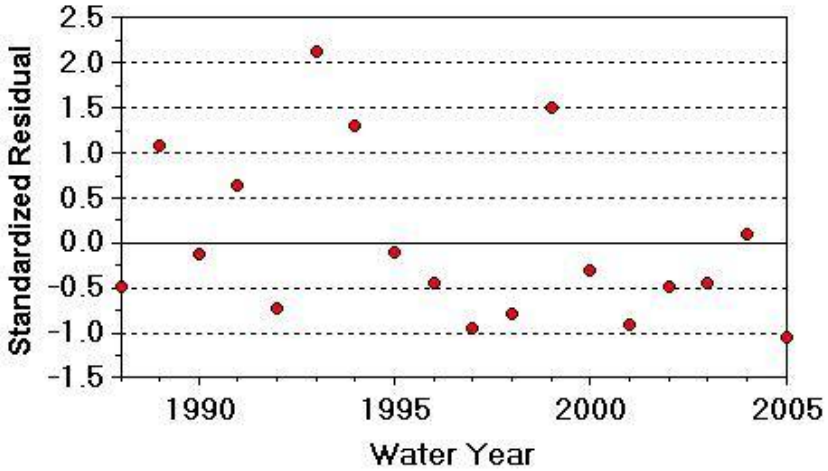

Figure 3.3 Standardized residuals from the regression of the STN abundance index against the Jersey Point salinity and the FMWT abundance index, plotted against the water year.

There is another aspect of the regressions that should be noted. A plot of JPEC against exports indicates a positive relationship (Figure 3.4). A regression of JPEC against exports does not give a significant result (t = 1.71 with 16 df, p = 0.106), but still there is an indication that JPEC and exports are positively related in the sense that JPEC tends to be high when exports are high.

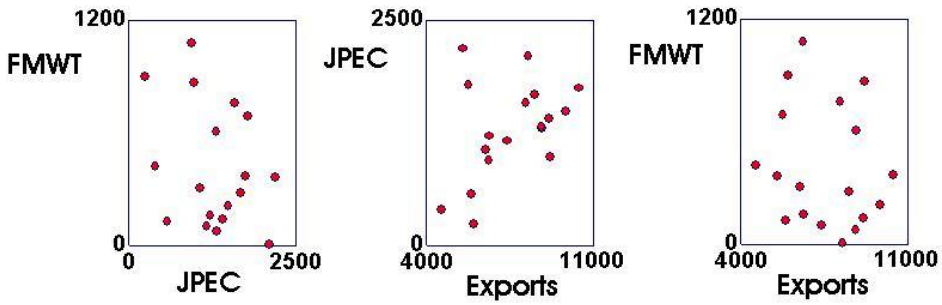

Figure 3.4 Relationships between the FMWT abundance index, the salinity at Jersey Point (JPEC), and the winter export rate.

Although the predictions from the regression equation relating the STN abundance index to the salinity at Jersey Point and the FMWT abundance index have tended to be low in recent years, the equation still gives a reasonably good fit to the data, as shown in Figure 3.5.

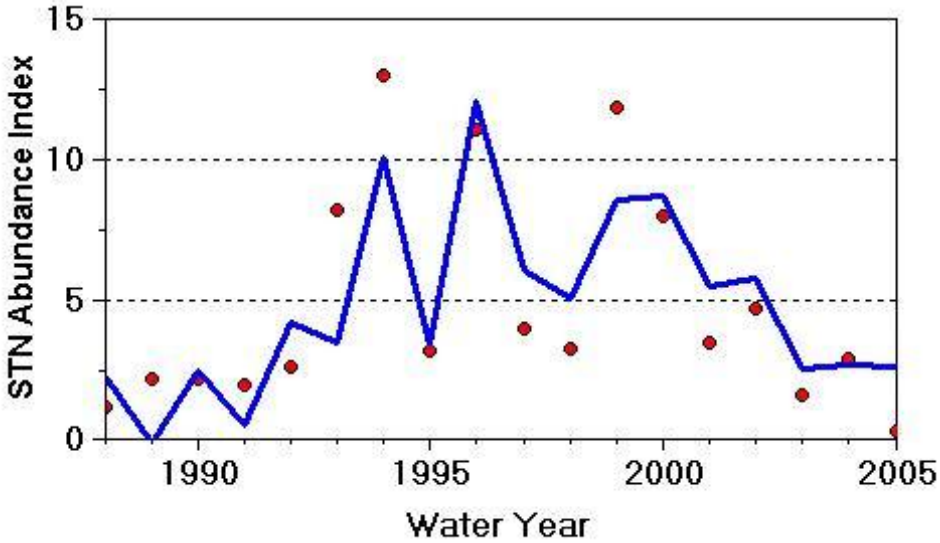

Figure 3.5 Observed (●) and fitted (—) STN abundance index values from the regression of STN abundance against the salinity at Jersey Point and the FMWT abundance index..

Conclusions

The regression equation that was fitted by Guerin *et al*. (2006) relating the STN abundance index to salinity at Jersey Point and the FMWT abundance index is correct. It accounts for about 72% of the variation in the data and is not significantly improved by adding water export rates as an explanatory variable. There is some indication that the residuals from the model may be related to winter export rates, and also that the salinity at Jersey Point may be related to winter export rates, but these effects are not significant.

4. Analyses Made by T. Swanson

Swanson (2005) states that her analyses were begun to further explore the results obtained by Herbold, and some early results obtained by Guerin. Swanson first considered the relationship between the STN abundance index and the following FMWT abundance index, and also the relationship between the FMWT index and the following STN index. Very highly significant relationships were found. Swanson also considered the relationship between exports and the delta smelt abundance indices. Her analyses suggest winter exports have a negative effect on adult delta smelt abundance as measured by the FMWT index, and that spring and summer exports have a negative effect on juvenile abundance, as measured by the STN index.

(a) Relationship Between Adults and Juvenile Delta Smelt Abundance

The first relationship considered by Swanson concerned the relationship between adult and juvenile abundance. This relationship was also examined by Miller (2005e, Figure 1), who found a significant relationship based on 11 years of data. Swanson considered all of the available data (1969-2004) and also a recent period (1987-2004). She found a significant relationship with all of the data but not with the reduced data.

The data for all of Swanson's analyses are in the file DS_Export_Analysis_for_Sheila.xls, dated January 20, 2006 and provided by Swanson. I checked the FMWT and STN abundance indices against those on the www.delta.dfg.ca.gov website and found them to be correct. In her analyses Swanson used logarithms to base 10 of the original index values. The untransformed values are shown in Table C2.

It can be verified that the regression equation relating log(STN) in a water year to the log(FMWT) value earlier in the same water year is

$$\text{Log(STN)} = -1.406 + 0.828[\text{Log(FMWT)}],$$

as stated by Swanson. This equation accounts for 34.1% of the variation in the Log(STN) values. The standard error of the estimated regression coefficient is 0.201, so it is very highly significant ($t = 4.13$ with 33 df, $p = 0.0002$).

Figure 4.1 shows the observed values of Log(STN) and the values predicted by the equation. The water years are shown in the figure, and it is notable that the 2005 result seems very extreme. Figure 4.2 shows a comparison between the observed values of Log(STN) and the values predicted from the regression equation, plotted against the water year . This figure also shows the standardized residuals from the regression (the observed minus expected value of Log(STN) divided by the estimated residual standard deviation. The standardized residuals should be mostly in the range from -2 to +2 and almost all within the range from -3 to +3. In this respect they are very satisfactory. However, the residuals do not seem to be random deviations from the expected values. Instead there

have been excursions above and below the expected values. In particular, the residuals are all positive for 1976-82, all negative for 1987-92, and all negative again for 2000-05.

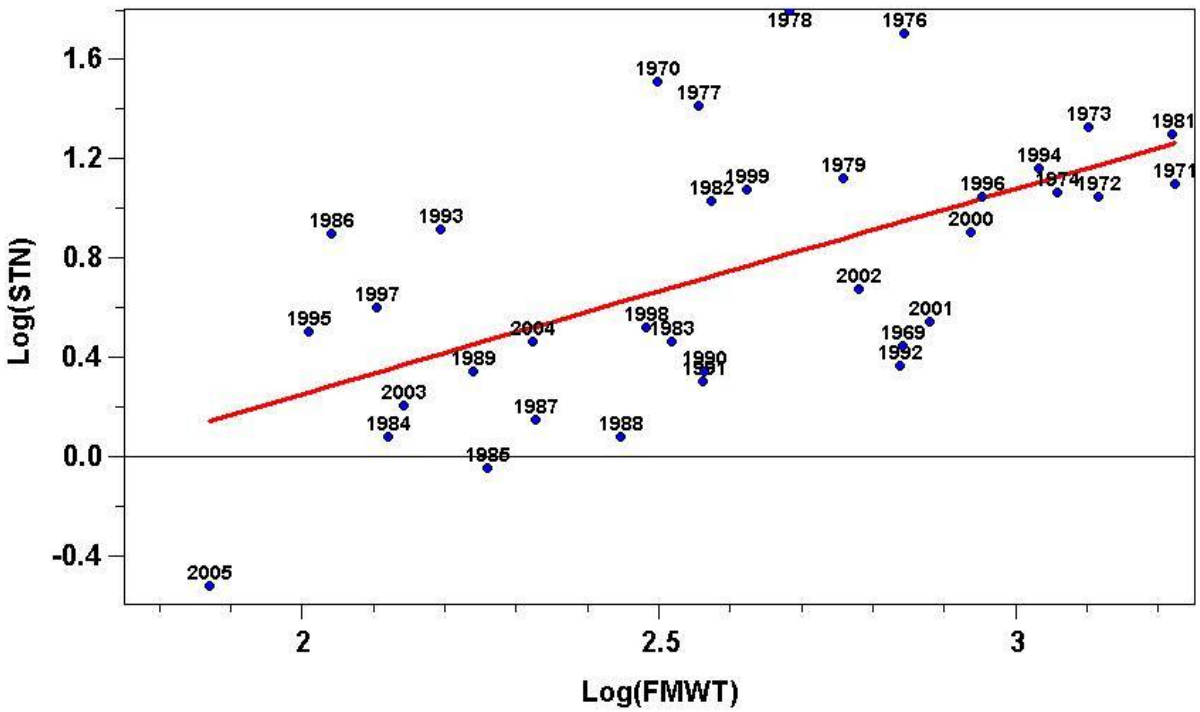

Figure 4.1 The observed and fitted relationship between Log(STN) and Log(FMWT). The years shown are the water years so that Log(FMWT) comes before Log(STN) in any water year.

The runs of positive and negative residuals suggest that the residuals are not independent, but instead are correlated to some extent. Either that, or there is a missing covariate that has values that can account for the pattern in the residuals. Out of interest, I tried fitting a model with correlated residuals using GenStat (Lawes Agricultural Trust, 2005). I considered correlation extending for a maximum of five years, but only obtained a significant model for the regression residual in one year being related to the regression residual in the previous year. The equation obtained for Log(STN) in water year i is

$$\text{Log}(\text{STN}_i) = -0.427 + 0.444[\text{Log}(\text{FMWT}_i)] + 0.466(e_{i-1}),$$

where e_{i-1} is the estimated regression residual in year i - 1. This means, for example, that if the regression residual is positive in one water year (i.e., the observed value of Log(STN) is greater than the expected value), then the predicted value of Log(STN) is increased in the following year. This equation accounts for 36.5% of the variation in Log(STN), which is slightly more than the 34.1% obtained from the ordinary regression of Log(STN) against Log(FMWT).

Allowing for the correlation in residuals generally reduces the significance of regression coefficients. In this case the regression coefficient is also reduced from 0.828 to 0.444. The standard error associated with the estimated coefficient of 0.444 is 0.212. This is now only just significant at the 5% level (t = 2.09 with 32 df, p = 0.045. On the other hand the coefficient of e_{i-1} has a standard error of 0.183, and is more significant (t = 2.55 with 32 df, p = 0.016).

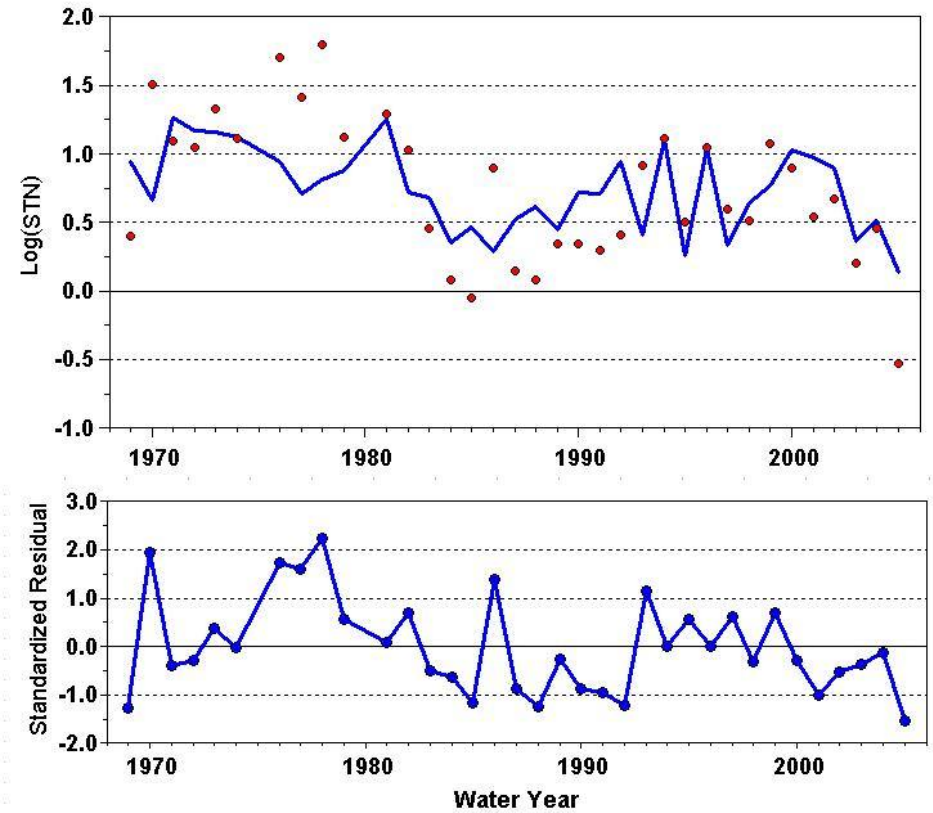

Figure 4.2 The top panel shows the observed values (●) of Log(STN) plotted against the water year, together with the expected values (—) from the regression of Log(STN) against Log(FMWT). The top panel shows the standardized residuals from the regression, also plotted against the water year.

Figure 4.3 shows the observed Log(STN) values compared to the expected values based on the ordinary regression of Log(STN) against Log(FMWT), and the model with an allowance for correlated residuals. The fits are not that different, although the model allowing for correlated residuals is a little more flexible in terms of taking into account the apparent excursions above and below the expected values. For both models the 2005 Log(STN) value seems very extreme.

It is hard to know which of the two models is better, although they both give a significant relationship between Log(STN) and Log(FMWT) values in the same water year. The pattern in the residuals suggests that they are correlated and a model allowing for this

gives a significant relationship between the value of Log(STN) in one water year and the regression residual in the previous water year. This model therefore seems reasonable, but it is not able to account completely for the pattern in residuals. Neither of the models accounts well seem for the changes in Log(STN) that have occurred since 2000.

It is possible that the relationship between Log(FMWT) and the previous Log(STN) changed over the time period being considered. Swanson (2005) estimated the relationship for the period 1987-2004 and suggested that it was weaker than the relationship estimated for the whole period. Alternatively, there may of course be an important covariate missing from the equation.

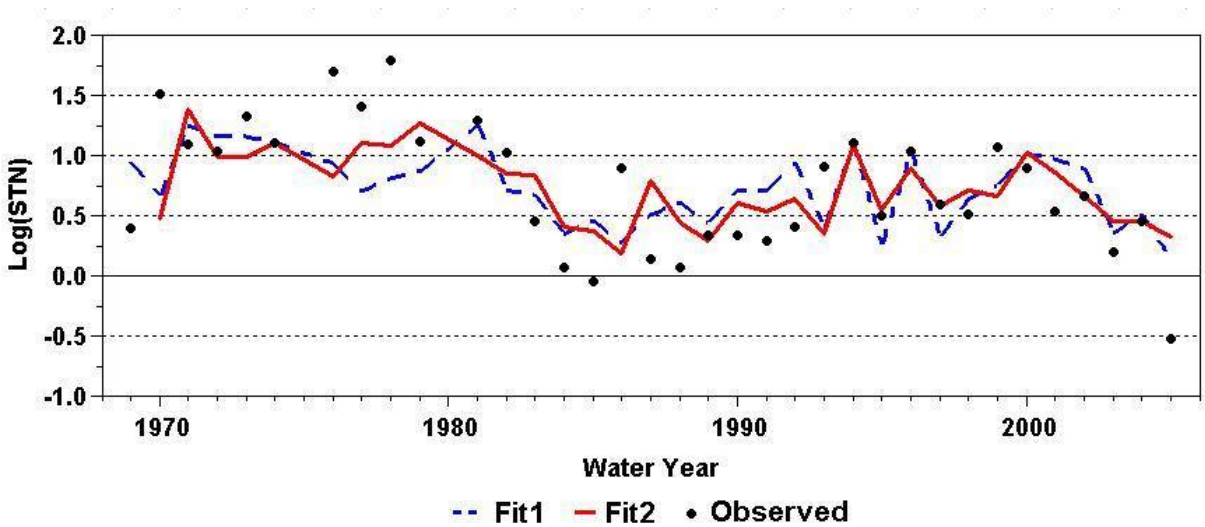

Figure 4.3 Comparison between the observed Log(STN) values, the fitted values (Fit1) from an ordinary regression of Log(STN) against Log(FMWT), and the fitted values (Fit2) from the regression with a model for the correlation between successive residuals.

Swanson (2005) also considered whether the Log(FMWT) values can be predicted from the previous Log(STN) values. Using the transformed data from Table C2 it is found that the estimated regression equation is

$$\text{Log(FMWT)} = 2.210 + 0.460[\text{Log(STN)}].$$

This accounts for 33.7% of the variation in Log(FMWT). The coefficient of Log(STN) has a standard error of 0.112, so that the coefficient is very highly significant ($t = 4.10$ with 33 df, $p = 0.0003$). This equation differs slightly from the one given by Swanson (2005) because I have been able to use the FMWT index value for the fall of 2005.

Figure 4.4 shows the observed values of Log(FMWT) plotted against the values of Log(STN), together with the fitted regression line. The point for 2005 is very extreme. Figure 4.5 shows the observed and fitted values of Log(FMWT) plotted against the calendar year. It also shows the standardized residuals, again plotted against the

calendar year. This figure shows patterns in the residuals just like the residuals from the regression of Log(STN) against Log(FMWT), although not so pronounced.

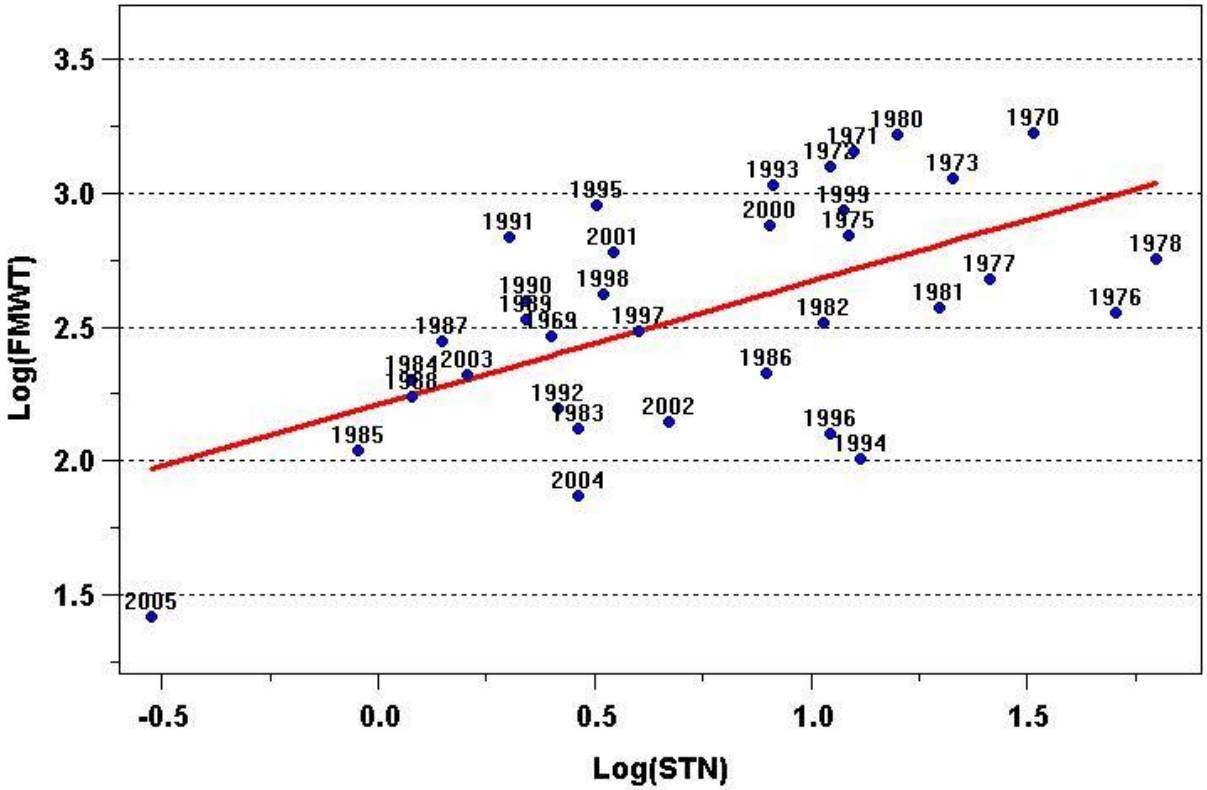

Figure 4.4 Log(FMWT) values plotted against Log(STN) values, with the fitted regression line shown. The calendar year is indicated for each of the observed Log(FMWT) values.

I tried fitting a regression model with correlated errors to see whether this fits better than the ordinary regression model. It turns out that there is a significant relationship between the Log(FMWT) value and the regression residual two years before. The estimated equation for calendar year i is

$$\text{Log}(\text{FMWT}_i) = 2.233 + 0.401[\log(\text{STN}_i)] + 0.038e_{i-1} + 0.460e_{i-2},$$

where e_i is the regression residual in year i. The standard error of the coefficient of Log(STN) is 0.135 so the coefficient is very highly significant ($t = 2.96$ with 31 df, $p = 0.006$). The standard errors of the coefficients of e_{i-1} and e_{i-2} are 0.192 and 0.190, respectively. The first coefficient is therefore not significant ($t = 0.20$ with 31 df, $p = 0.843$), but the second is significant ($t = 2.43$ with 31 df, $p = 0.021$).

It is not clear why Log(FMWT) should be related to the regression residual two years before, but not related much to the regression residual in the previous year. To a large extent it seems to be related to the unusual oscillating values of the FMWT index in the

early 1990s. However, it is interesting to find that this last equation accounts for 45.6% of the variation in the data while the ordinary regression equation accounts for only 33.7%.

Figure 4.6 shows plots of the observed values of Log(FMWT) plotted together with the expected values for the ordinary regression equation, and also the expected values from the model allowing for correlated residuals. Although the model allowing for correlated residuals fits better, it does not account for the low values in Log(FMWT) in 2004 and 2005.

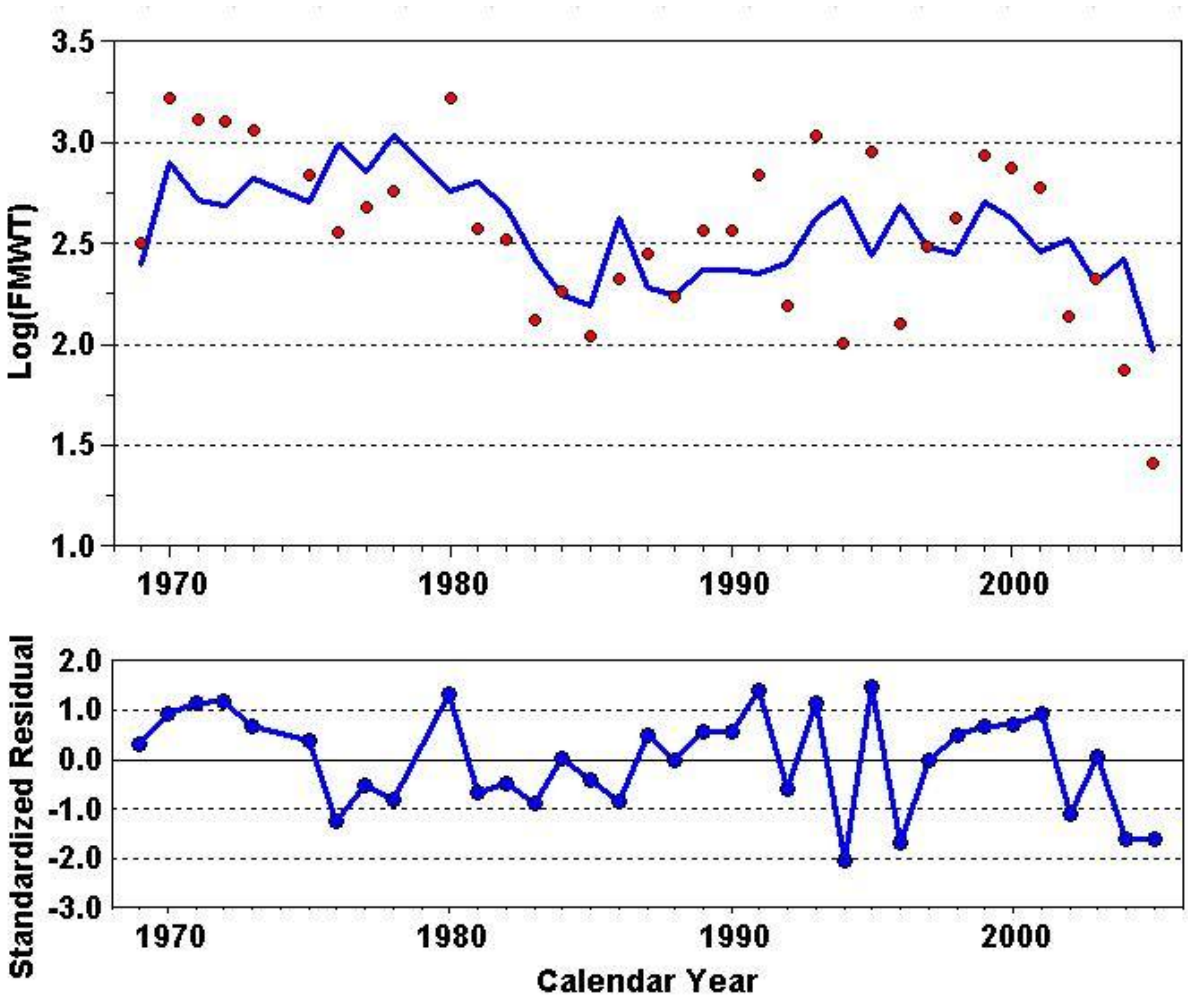

Figure 4.5 Observed (●) and expected (—) values of Log(FMWT) from the regression of Log(FMWT) against Log(STN), plotted against the calendar year (top panel), with the standardized residuals also plotted (bottom panel).

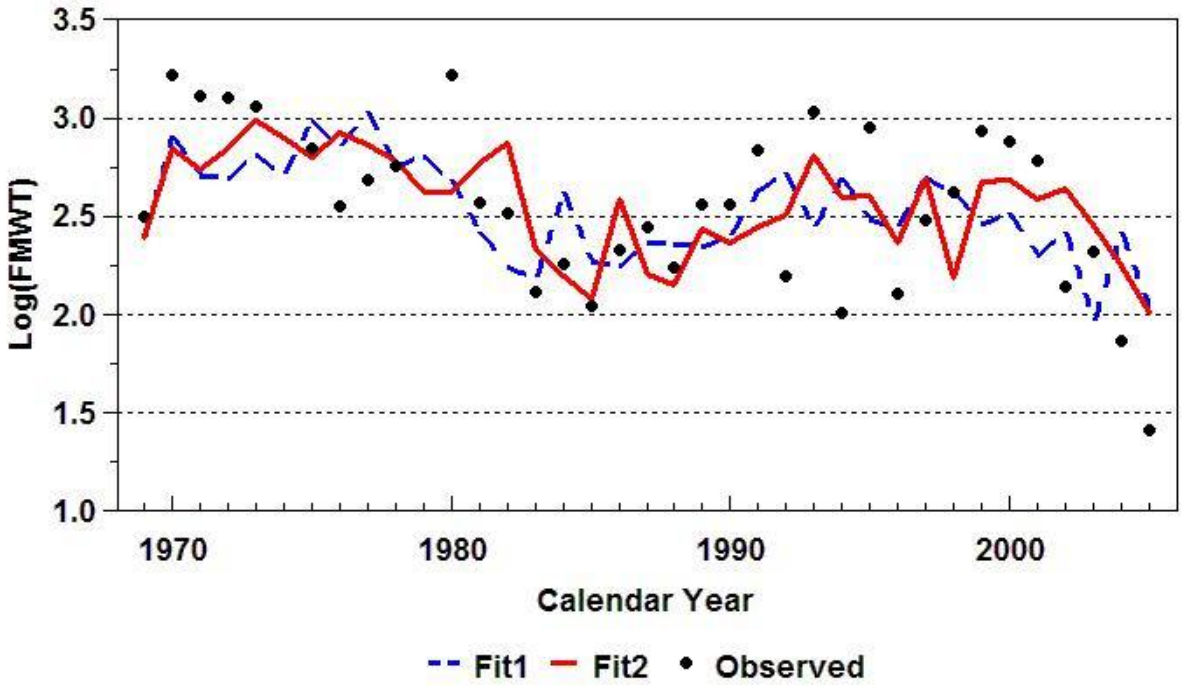

Figure 4.6 Comparison between the observed Log(FMWT) values, the fitted values (Fit1) from an ordinary regression of Log(FMWT) against Log(STN), and the fitted values (Fit2) from the regression with a model for the correlation between successive residuals.

Conclusions

The results of the regression of Log(STN) values against Log(FMWT) values described by Swanson (2005) are correct. There is clear evidence of a positive relationship between the two indices in the same water year. There are, however, apparent patterns in the regression residuals which suggest that these may be correlated, the patterns are related to the values of a missing covariate, or the equation changed over the period being considered. In particular, it is interesting to note that the residuals have been negative since 2000, and the residual for 2005 is the most extreme that has been observed. When a regression with correlated errors is considered it accounts for slightly more of the variation in the data than the ordinary regression, at the expense of estimating one more parameter. It does not completely eliminate the pattern in residuals.

The results of the regression of Log(FMWT) values against the previous Log(STN) values given by Swanson (2005) is also correct, but differs slightly from the equation given here because I used data for 2005 that was not available when Swanson did her analysis. There is clear evidence of a relationship, but the equation also has some apparent patterns in the residuals. A slightly better fit to the observed data can be obtained using a regression with correlated errors, but this still does not account for the low Log(FMWT) values in 2004 and 2005, and the estimated correlation structure in the residuals is hard to account for.

(b) The Effect of Winter Exports on the STN Abundance Index

Swanson (2005) examined whether logarithms to base 10 of the STN juvenile delta smelt abundance index values are related to winter exports. For this purpose winter was defined as December to March rather than November to March as used by Herbold *et al*. (2006). It is stated by Swanson that using other definitions of winter yields similar statistically significant results, but I did not check this.

A regression of Log(STN) values against exports yields the equation

$$\text{Log(STN)} = 1.3864 - 0.0949(\text{WExp}),$$

where WExp is the average daily flow rate (cfs) in winter (December to March) divided by 1000. This is similar to the equation given by Swanson. It accounts for 17.5% of the variation in Log(STN). The standard error of the coefficient of WExp is 0.0352 so the estimated coefficient is highly significant ($t = -2.73$ with 35 df, $p = 0.0099$).

Figure 4.7 shows the observed and expected Log(STN) values plotted against WExp, with the water year also shown. The extremely low value for 2005 is very apparent. Figure 4.8 shows the observed and expected values for Log(STN) plotted against the water year, with the standardized residuals also shown. Some patterns in the residuals are apparent from Figure 4.8. In particular, the residuals were all positive for the period 1973-82, and all but one residual is negative for the period 1983-92, suggesting that there is an important covariate missing from the equation, the residuals are correlated, or the relationship between Log(STN) and exports was not constant over the whole of the period being studied.

A model was estimated allowing for the regression residuals to be correlated, as was done for the regressions described above. It turns out that there is a very significant relationship between the value of Log(STN) and the regression residual from the previous water year. The estimated equation for water year i is

$$\text{Log(STN}_i) = 0.8070 - 0.0160(\text{WExp}) + 0.587e_{i-1},$$

where e_i is the regression residual in water year i. This equation accounts for 33.3% of the variation in the data, which is nearly twice the variation accounted for by the ordinary regression equation. The standard error for the coefficient of WExp is 0.0383, so this coefficient is not at all significant ($t = -0.42$ with 34 df, $p = 0.677$). However, the standard error of the coefficient of e_{i-1} is 0.160. This coefficient is therefore extremely significant ($t = 3.68$ with 34 df, $p = 0.0008$).

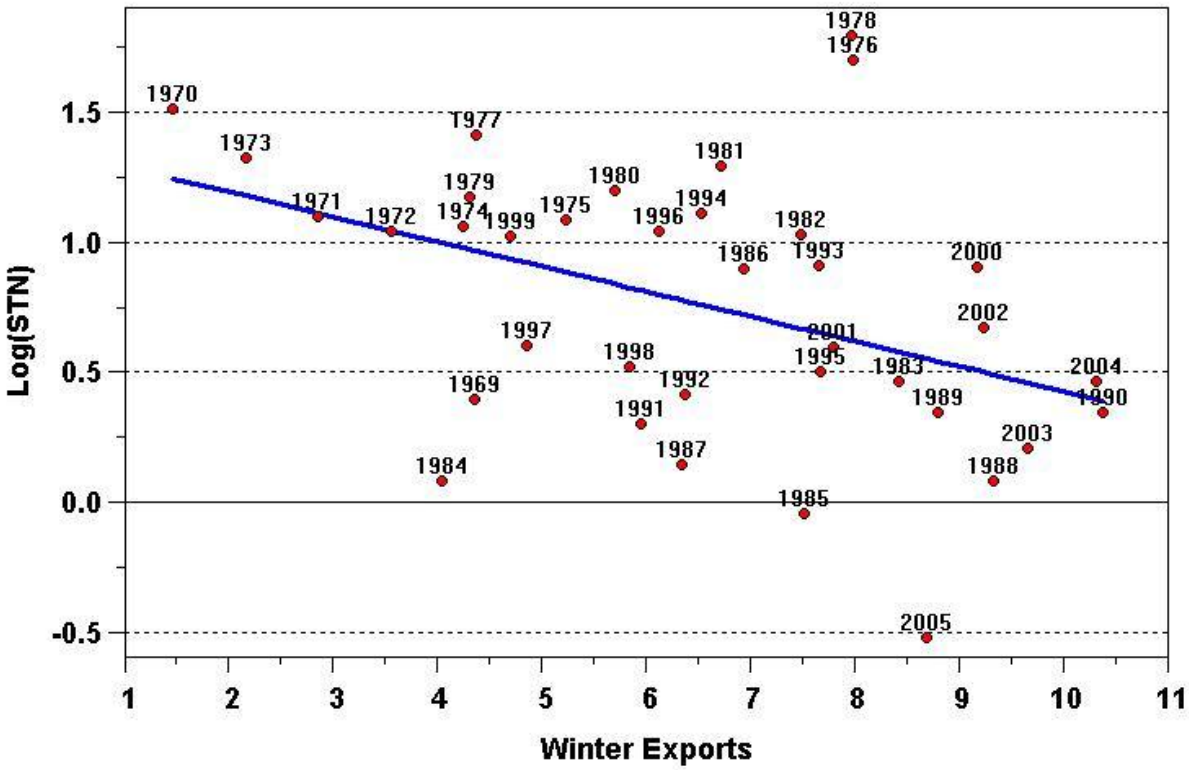

Figure 4.7 Log(STN) values plotted against winter exports, with the fitted regression line shown. The water year is indicated for each of the observed Log(STN) values.

Figure 4.9 shows the observed values of Log(STN) plotted against the water year and also the expected values from the ordinary regression of Log(STN) against WExp, and the expected values from the regression with correlated residuals. The regression with correlated residuals accounts for more of the variation than the ordinary regression, but is still not completely successful in accounting for the high Log(STN) values for 1973-82 and the mostly low Log(STN) values for 1983-92. The very low 2005 Log(STN) value is also not accounted for at all.

I investigated the idea that there has been a step change in the relationship between winter exports and Log(STN) at some time between 1969 and 2005. In fact, alternative analyses of the data (Manly, 2005) suggest that there may have been more than one change but for simplicity only one change will be considered here. Based on Figure 4.8 if there was one change then the obvious time is between 1982 and 1983. This is therefore where the change is assumed to have occurred.

A regression allowing the mean of Log(STN) to be different for the periods 1969-82 and 1983-05 gives an extremely significant fit to the data. It accounts for 48.8% of the variation in Log(STN), which is very extremely significant ($t = 5.78$ with 35 df, $p < 0.0001$). Adding a constant effect of exports into the model gives a non-significant effect ($t = -0.25$ with 34 df, $p = 0.803$), and adding in an export effect that varies with the two periods considered

also gives a non-significant effect (F = 1.02 with 2 and 33 df, p = 0.373). The two-phase model fits better than the ordinary regression of Log(STN) against winter exports (only 17.5% of variation accounted for), and also better than the regression with correlated residuals (33.3% of variation accounted for). The model is very simple, it says that the expected value of Log(STN) for 1969-82 is 1.224 while for 1983-05 the expected value is 0.481.

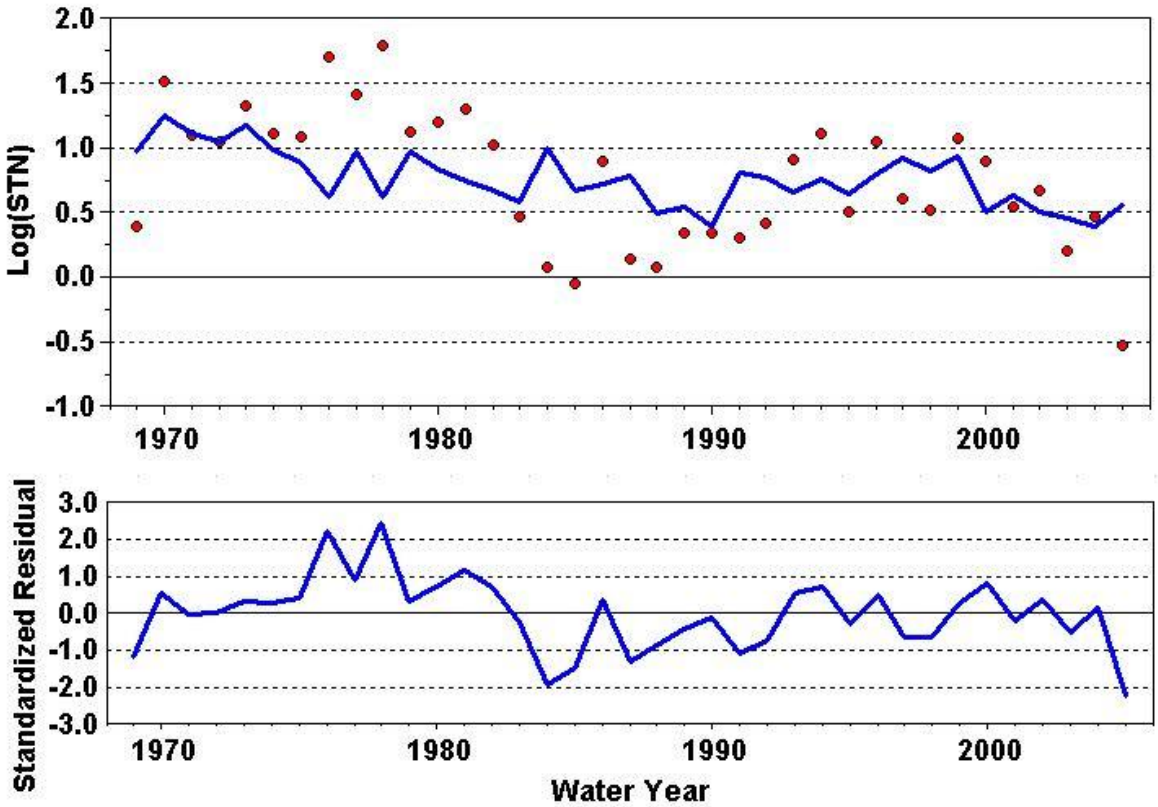

Figure 4.8 Observed (●) and expected (—) values of Log(STN) from the regression of Log(STN) against WExp, plotted against the calendar year (top panel), with the standardized residuals also plotted (bottom panel).

Although the model accounts for nearly half of the variation in the Log(STN) values, it is still not accounting for systematic variation in these values. This is shown by Figure 4.10 where the observed and expected Log(STN) values are shown. For the period 1969-82 the residuals look fairly random. However, for 1983-05 there are generally low values of Log(STN), followed by high values, followed by low values again. These changes are not accounted for by export effects, so something else seems to have been involved.

The lack of significance of export effects is easy to understand from the plot in Figure 4.11. This shows the standardized residuals from the model plotted against the values of winter exports. If exports have a significant negative effect then this should show up in the

residuals tending to be positive with low exports and negative with high exports. This is not apparent either for 1969-82 or 1983-05. The result for 2005 does show up as very extreme again.

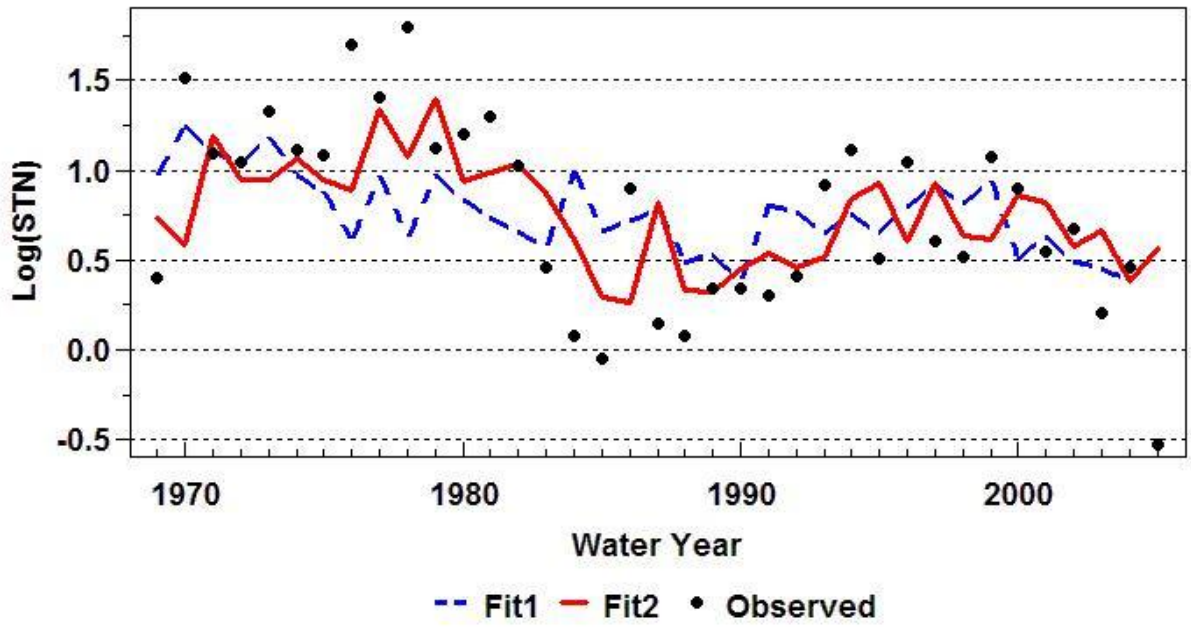

Figure 4.9 Comparison between the observed Log(STN) values, the fitted values (Fit1) from an ordinary regression of Log(STN) against winter exports, and the fitted values (Fit2) from the regression with correlated residuals.

Given the systematic changes in the residuals shown in Figure 4.10 it might be expected that a model with correlated residuals would fit better than one that assumes no relationship between residuals. In fact, this is not the case. I tried adding correlated residuals to the model but did not find any significant effect. The pattern in the residuals for 1983-05 is therefore apparently due to one or more unmeasured covariates rather than correlation in the residuals.

Conclusions

The apparent relationship between Log(STN) values and the prior winter exports over the period 1969 to 2005 seems questionable. There are patterns in the regression residuals that indicate correlation in these residuals, a missing covariate, or change with time in the mean of the Log(STN) values. If correlated residuals are allowed then the estimated effect of winter exports is small and not at all significant. If the mean of Log(STN) is assumed to change between 1982 and 1983 then the estimated change is highly significant and this simple model accounts for 48.8% of the variation in Log(STN), which is far more than the variation accounted for by any of the other models considered. Given a change in the mean of Log(STN) between 1982 and 1983 there is no evidence

that Log(STN) values are related to winter exports. This is confirmed by Figure 4.11 that indicates that the residuals from the simple model are not related to exports. Nevertheless, systematic patterns in the residuals suggest that Log(STN) may be determined to some extent by some unmeasured covariate.

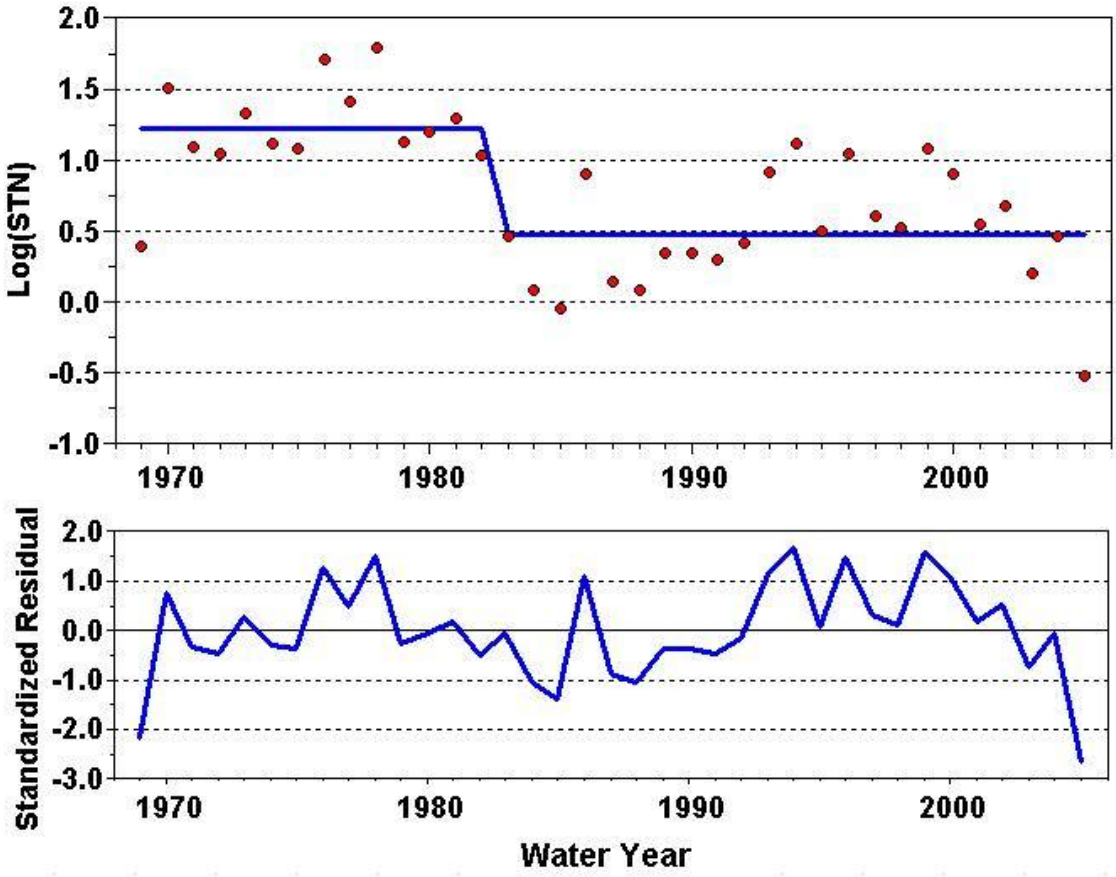

Figure 4.10 Observed (●) and expected (—) values of Log(STN) from the two period model for Log(STN), plotted against the water year (top panel), with the standardized residuals also plotted (bottom panel).

(c) The Effect of Winter Exports on the FMWT Abundance Index

Swanson (2005) also related logarithms to base 10 of the FMWT sub-adult delta smelt abundance index values to winter exports. Based on the data shown in Table C2 the equation is

$$\text{Log(FMWT)} = 3.077 - 0.081(\text{WExp}),$$

where, as before, WExp is the average export rate (cfs) December to March divided by 1000. The value of WExp is for the water year prior to the FMWT water year. This

equation differs slightly from the one given by Swanson (2005) because I have used the Log(FMWT) value for 2005 that was not available to Swanson.

The equation accounts for 24.7% of the variation in Log(FMWT) values. Swanson (2005) stated that her equation only accounted for 2.4% of the variation, but this should have been 24%. The standard error associated with the coefficient of WExp is 0.0240 in the equation given above. The coefficient is therefore highly significant (t = -3.39 with 35 df, p = 0.0017).

Figure 4.12 shows the observed and expected values of Log(FMWT) plotted against the winter exports, with the calendar year for Log(FMWT) values also shown. As usual, the observed value for water year 2005 appears to be very extreme. Figure 4.13 shows the observed and expected values plotted against the water year for exports, together with the standardized residuals from the regression. Patterns in the residuals are apparent, with ten positive residuals from 1970 to 1982 and all negative residuals from 1983 to 1988.

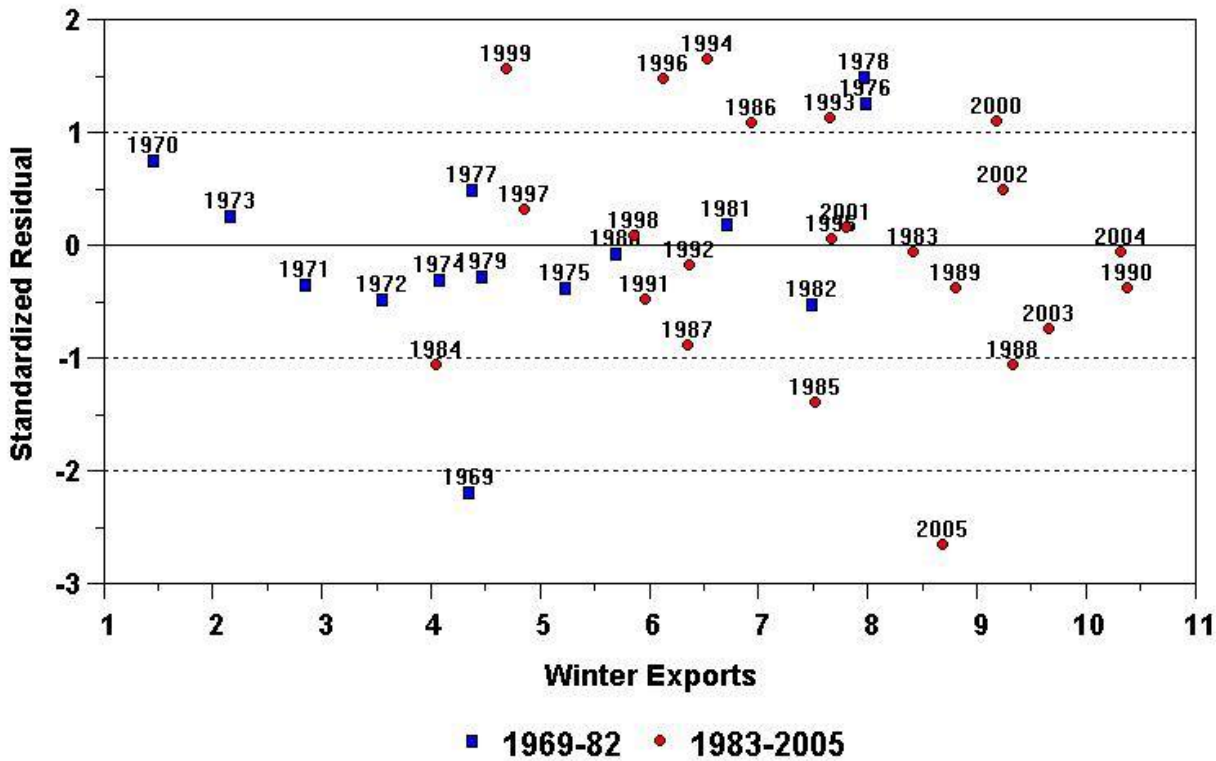

Figure 4.11 Standardized residuals plotted against winter exports for the simple model that assumes different mean values for Log(STN) for 1969-82 and 1983-05. The water year is indicated for each of the observed Log(STN) values.

Because of the patterns in the residuals a regression with correlated errors was considered for the data. It was found that the Log(FMWT) value in water year i can be described by the equation

$$\text{Log}(\text{FMWT}_i) = 2.802 - 0.0462(\text{WExp}_i) + 0.177e_{i-1} + 0.455e_{i-2},$$

where e_i is the regression residual in water year i. This equation accounts for 36.4% of the variation in Log(FMWT) values. The standard error associated with the coefficient of WExp is 0.0300. This coefficient is therefore not significant at the 5% level (t = -1.54 with 33 df, p = 0.133). The standard error of the coefficient of e_{i-1} is 0.177, so this coefficient is also insignificant (t = 1.00 with 33 df, p = 0.325). However the standard error associated with the coefficient of e_{i-2} is 0.183, so this coefficient is significant (t = 2.48 with 33 df, p = 0.018). It is not clear why the Log(FMWT) values should depend on the regression residuals two years before although, as noted before the oscillating values of the FMWT index in the early 1990s seem to be largely responsible.

Figure 4.14 shows the observed values of Log(FMWT) plotted against the water year, with the expected values from the ordinary regression of Log(FMWT) against WExp and the regression with correlated residuals. The model with correlated residuals does fit better, but there are still eight positive residuals for the period 1970 to 1982, and the low Log(FMWT) values in 2004 and 2005 are not accounted for.

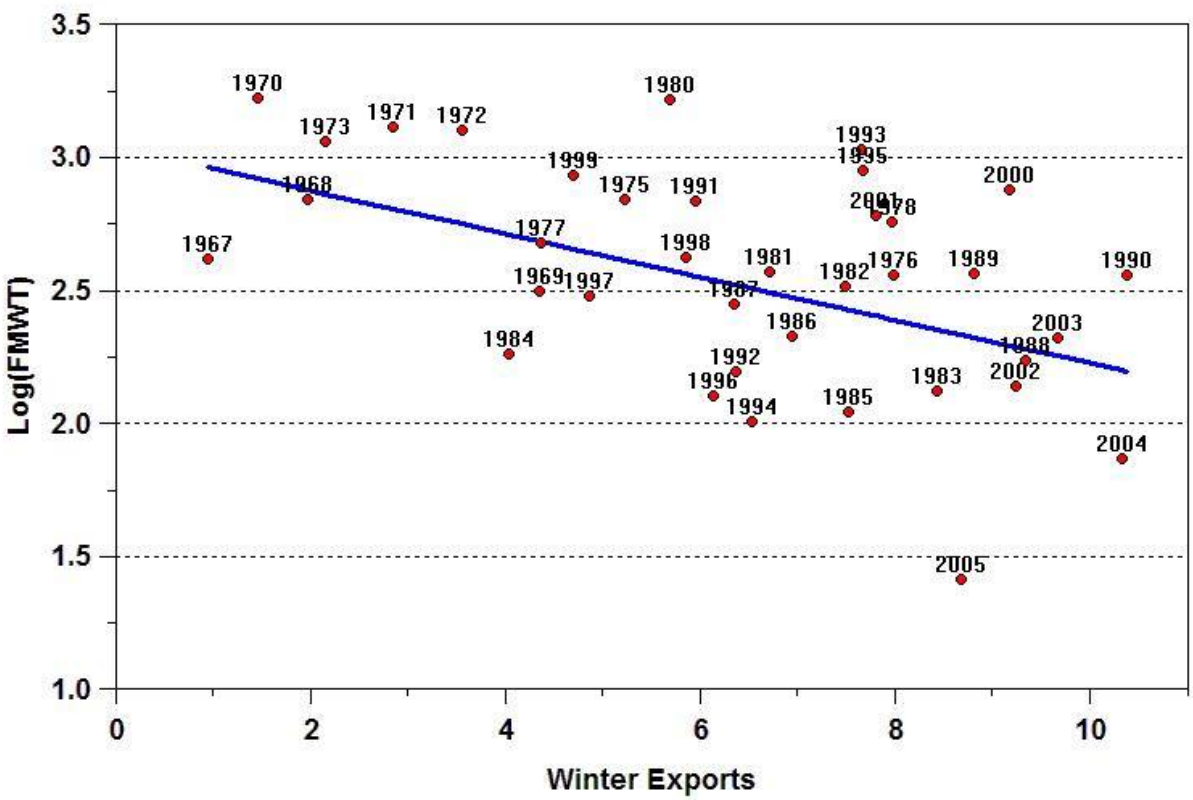

Figure 4.12 Log(FMWT) values plotted against winter exports, with the fitted regression line shown. The calendar year is indicated for each of the observed Log(FMWT) values.

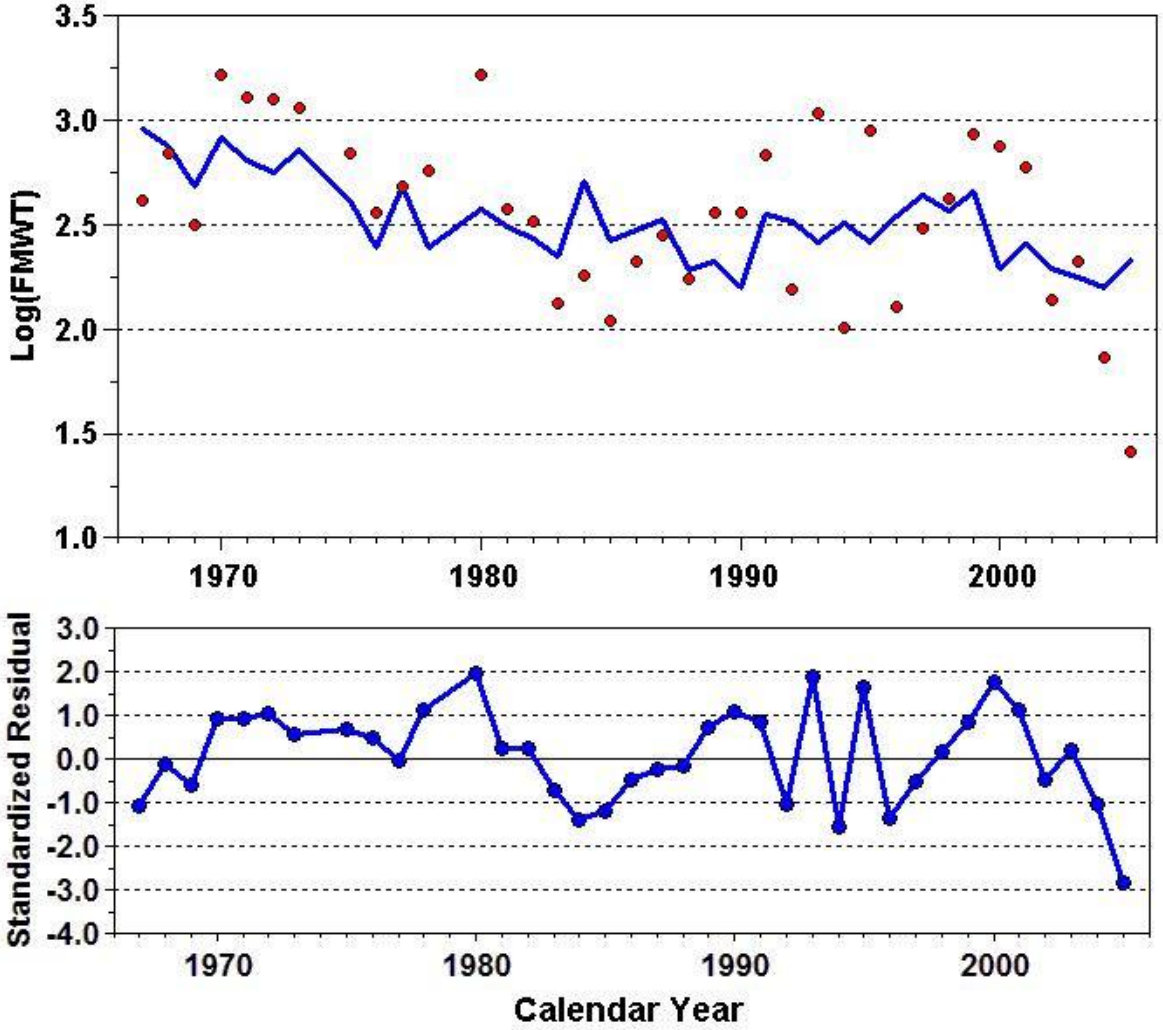

Figure 4.13 Observed (●) and expected (—) values of Log(FMWT) from the regression of Log(FMWT) values against winter exports, plotted against the calendar year (top panel), with the standardized residuals also plotted (bottom panel).

The possibility of a change in the mean of the Log(FMWT) values was also considered, as was done with the Log(STN) values. Based on the standardized residuals shown in Figure 4.13 it is appropriate to consider the two periods 1967-82 and 1983-05. The change point is then the same as what was used with the Log(STN) values.

A model that just assumes different expected values for Log(FMWT) before and after the change point was considered first. This accounts for 26.6% of the variation in Log(FMWT) which is highly significant ($t = -3.56$ with 35 df, $p = 0.0011$). Adding an effect of winter exports which is the same for both periods does not quite give a significant change ($t = -1.70$ with 34 df, $p = 0.098$). Allowing the effect of winter exports to vary with the period then gives a non-significant change ($t = 0.07$ with 33 df, $p = 0.944$). The model

with different expected values for Log(FMWT) therefore seems reasonable for the data, possibly with a constant effect of winter exports.

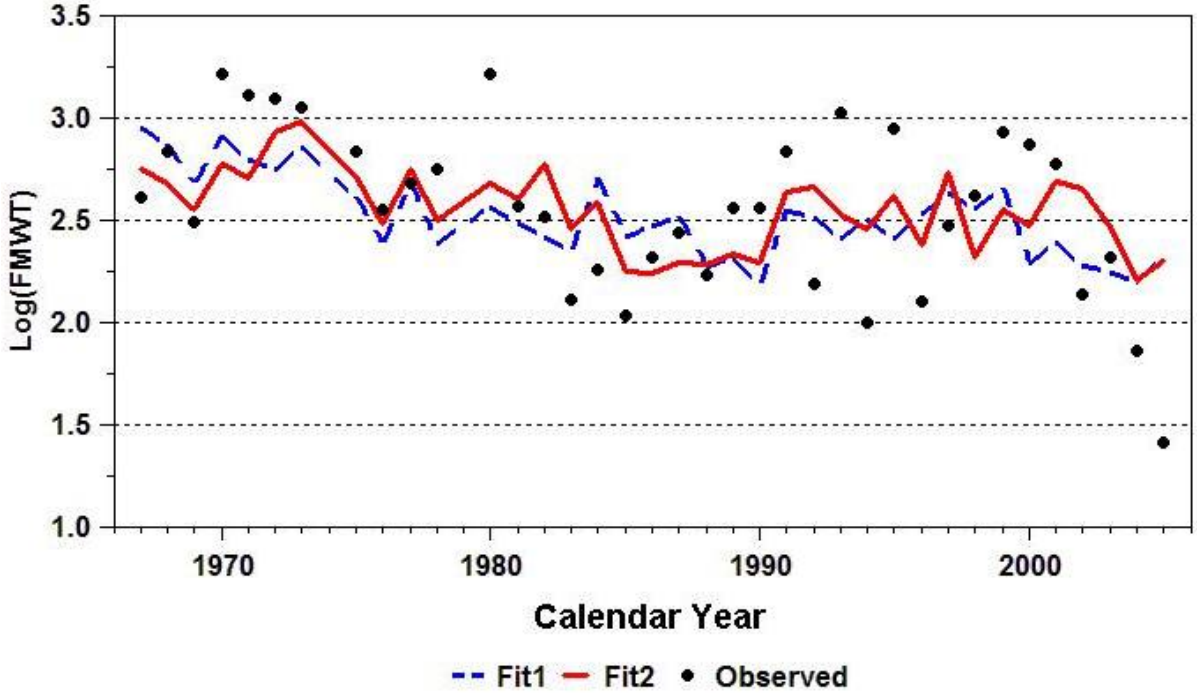

Figure 4.14 Comparison between the observed Log(FMWT) values, the fitted values (Fit1) from an ordinary regression of Log(FMWT) against winter exports, and the fitted values (Fit2) from the regression with correlated residuals.

The model with a constant effect of exports accounts for 32.4% of the variation in Log(FMWT). The regression equation is

$$\text{Log(FMWT)} = 3.046 - 0.286(\text{Period2}) - 0.048(\text{Exports}),$$

where Period2 equals 1 for the period 1983-2005 but is otherwise 0. The standard errors for the coefficients of Period2 and Exports are 0.146 and 0.029, respectively. Figure 4.15 shows the fit of this model, together with the standardized residuals. The fit is a little better than the fit of the model that is shown in Figure 4.13 which does not have the Period2 effect in it. However, the low FMWT index values in 2004 and 2005 are still not accounted for.

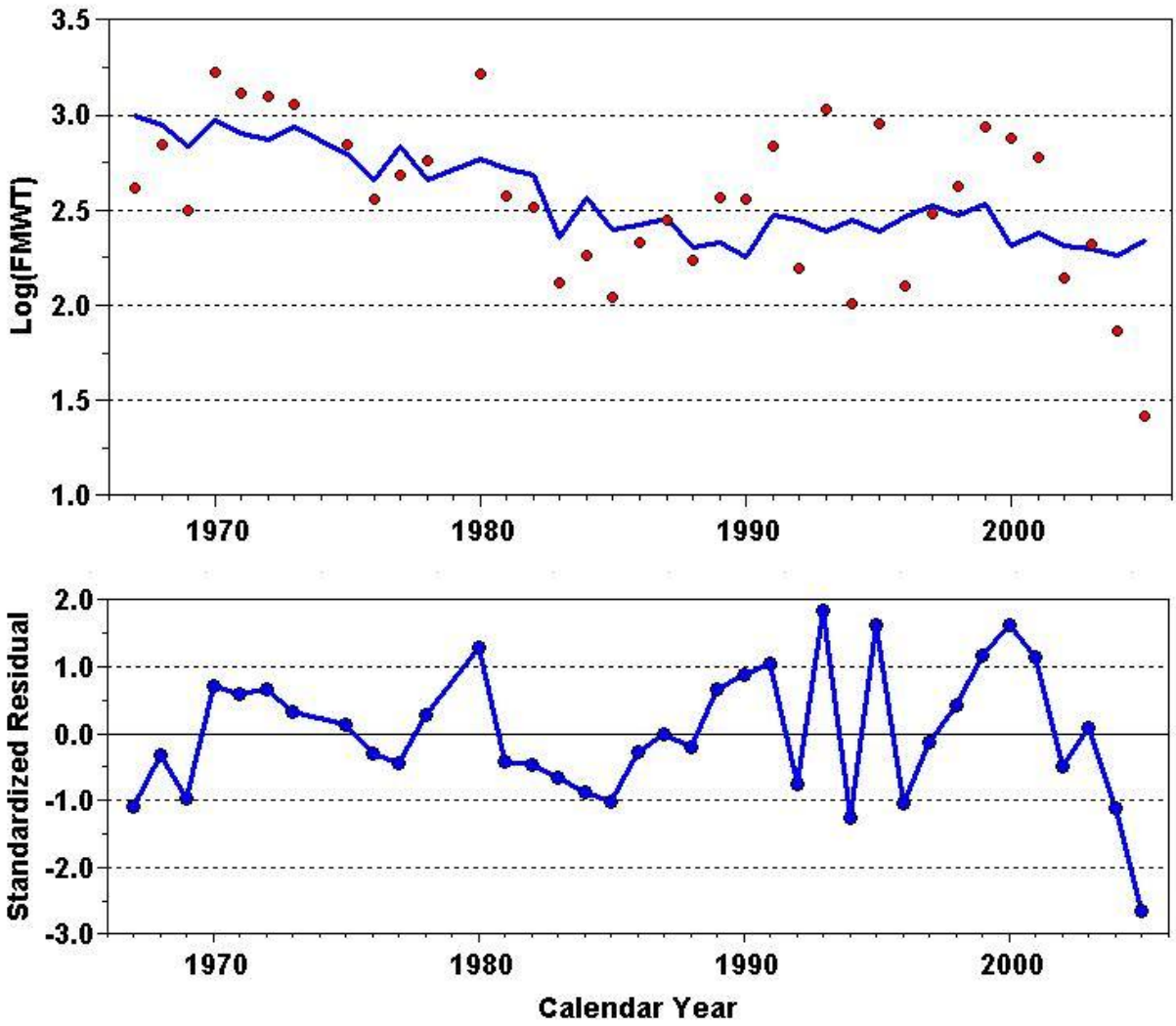

Figure 4.15 Comparison between the observed Log(FMWT) values (●) and the fitted values (—) from the regression of Log(FMWT) against winter exports with an allowance for a change in the mean between 1982 and 1983 (top graph), with standardized residuals also shown (lower graph).

The possibility of correlated residuals was considered, starting with the model including an allowance for an export effect that may not be the same for the two time periods being considered. It was found that Log(FMWT) values are significantly related to the regression residual two years before. With the model with correlated residuals the effect of allowing different export effects in the two different time periods is not significant ($t = 1.52$ with 31 df, $p = 0.139$), and was therefore removed from the model. A constant export effect was also not significant ($t = -1.12$ with 32 df, $p = 0.271$), and was removed from the model. The final equation for the Log(FMWT) value in water year i was then

$$\text{Log}(\text{FMWT}_i) = 2.779 - 0.442(\text{Period2}) + 0.147e_{i-1} + 0.452e_{i-2},$$

where e_i is the regression residual for Log(FMWT) in water year i, and Period2 is equal to 1 for the period 1983-05 or is otherwise zero. This accounts for 40.5% of the variation in Log(FMWT). The standard error associated with the coefficient of Period2 is 0.202, so the coefficient is significant (t = -2.18 with 33 df, p = 0.037). The standard error associated with the coefficient of e_{i-1} is 0.180. This coefficient is therefore not significant (t = 0.82 with 33 df, p = 0.418). However the standard error associated with the coefficient of e_{i-2} is also 0.180, so that it is significant (t = 2.44 with 33 df, p = 0.020).

Figure 4.16 shows the observed and expected values of Log(FMWT) from this model. Generally it seems to fit quite well, but does not account for the low values of Log(FMWT) since 2002. However, a concern about this model is the assumed relationship between Log(FMWT) and the regression residual two years before, which appears to be largely due to the oscillating FMWT values in the early 1990s, which are hard to explain. For this reason the previous model for Log(FMWT) with a change in mean 1982-83 without correlated residuals may be preferred, with or without an effect for exports.

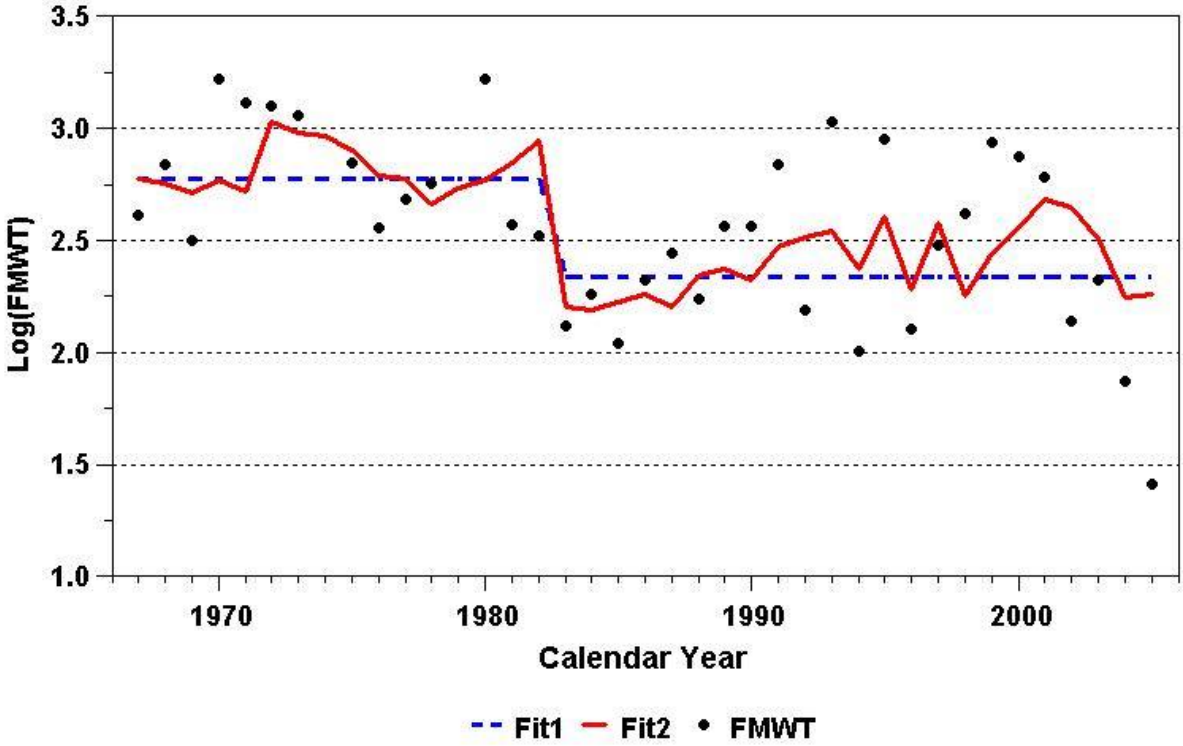

Figure 4.16 Comparison between the observed Log(FMWT) values, the fitted values (Fit1) from the model with different expected values for the periods 1967-82 and 1983-05, and the fitted values (Fit2) from the regression with correlated residuals.

Conclusions

The situation for Log(FMWT) values related to prior winter exports seems complicated. It seems strange, to begin with, that a simple regression of Log(FMWT) values against winter exports accounts for 24.7% of the variation in the dependent variable, whereas a simple regression of Log(STN) values against winter exports only accounts for 17.5% of the variation in the data. This seems to be the wrong way round because the STN abundance index is determined after the winter exports but before the FMWT abundance index, which suggests that any export effect should show up more strongly in the STN index.

The regression of Log(FMWT) values against the winter export rate is highly significant, but there are patterns in the residuals. If these patterns are modeled assuming correlated regression residuals then the correlation in regression residuals is found to be significant and the estimated regression accounts for 36.4% of the variation in the data. There is no longer a significant effect of winter exports, but still some patterns in the regression residuals. Also, the model assumes that Log(FMWT) values are related to the regression residuals two years before, which is hard to account for.

Another possibility is to assume that the mean of Log(FMWT) changed at some point between 1967 and 2005, in which case the most obvious change point is between 1982 and 1983. Assuming a change in the mean of Log(FMWT) at that point accounts for 26.6% of the variation in Log(FMWT) values. There is then some indication of an effect of winter exports assuming that this was constant over the full period 1967 to 2005, with this effect approaching significance at the 5% level.

There are still patterns in the residuals for the model assuming a change in the mean of Log(FMWT) between 1982 and 1983. If these are modeled assuming correlated regression residuals then 40.5% of the variation in Log(FMWT) values can be accounted for without allowing for winter export effects. There is, however, still an assumed relationship between the Log(FMWT) index values and the regression residuals two years before that is hard to account for. Therefore the model with a change in the mean between 1982 and 1983 but without correlated residuals may be preferred to this model, with or without an export effect.

None of the models considered can account for the very low FMWT values in 2004 and 2005.

(d) Effect of Spring and Summer Exports on the STN Abundance Index

The final analysis considered by Swanson (2005) related Log(STN) to the total exports from March to July in total acre-feet in the same year as the STN abundance index. The total export data are shown in Table C2. These came from the file

DS_Export_Analysis_for_Sheila.xls provided by Swanson on January 20, 2006, and have not been checked against an independent source.

The ordinary regression equation relating Log(STN) to the total exports is correctly given by Swanson (2005) as

$$\text{Log(STN)} = 1.543 - 0.453(\text{TExp})$$

where TExp is the total March to July exports in acre-feet divided by 1000. This equation accounts for 14.4% of the variation in the Log(STN) values. The standard error of the coefficient of TExp is 0.187 so that the coefficient is highly significant ($t = -2.42$, $p = 0.021$).

Figure 4.17 shows the observed values of Log(STN) plotted against the values of TExp, together with the fitted regression line. The regression looks reasonable, but with the 2005 result looking extreme, as usual. Figure 4.18 shows the observed and expected Log(STN) values plotted against the calendar year, with standardized residuals also shown. This gives a different picture. The regression equation under-estimates all but one of the Log(STN) values before 1983 and over-estimates most of the values from then on. The consistent under-estimation before 1983 suggests that this is not the result of correlated regression residuals. As with the other regressions considered above, it seems that the mean of the Log(STN) values may have changed between 1982 and 1983.

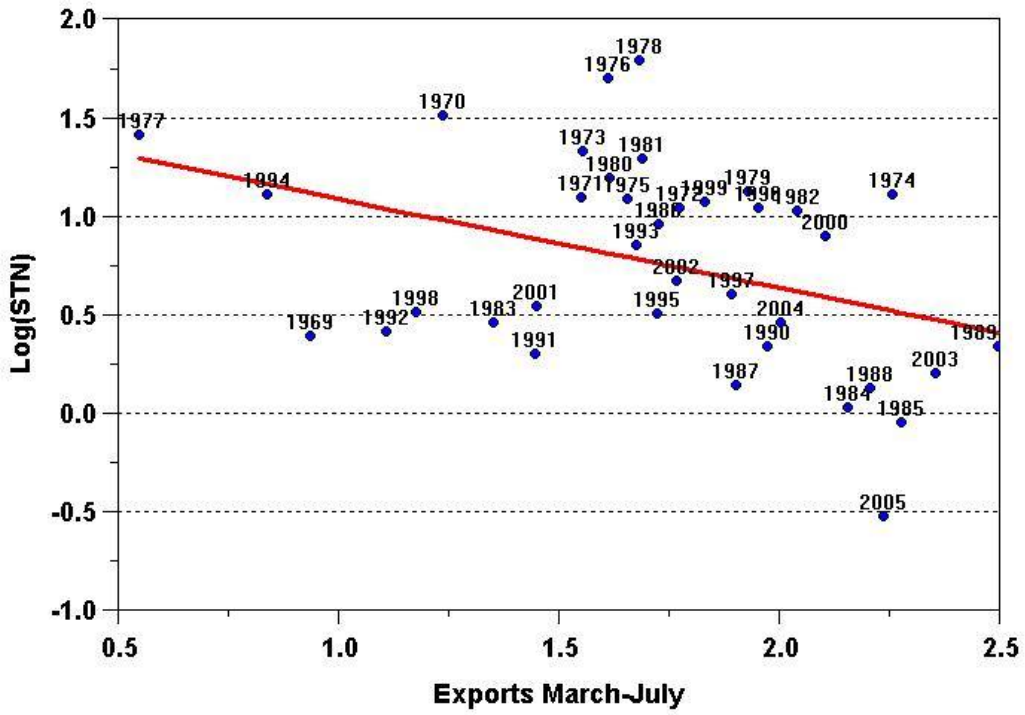

Figure 4.17 Values of Log(STN) plotted against the total March to July exports in total feet divided by 1000, with the fitted regression line also shown, and the year when the data were recorded.

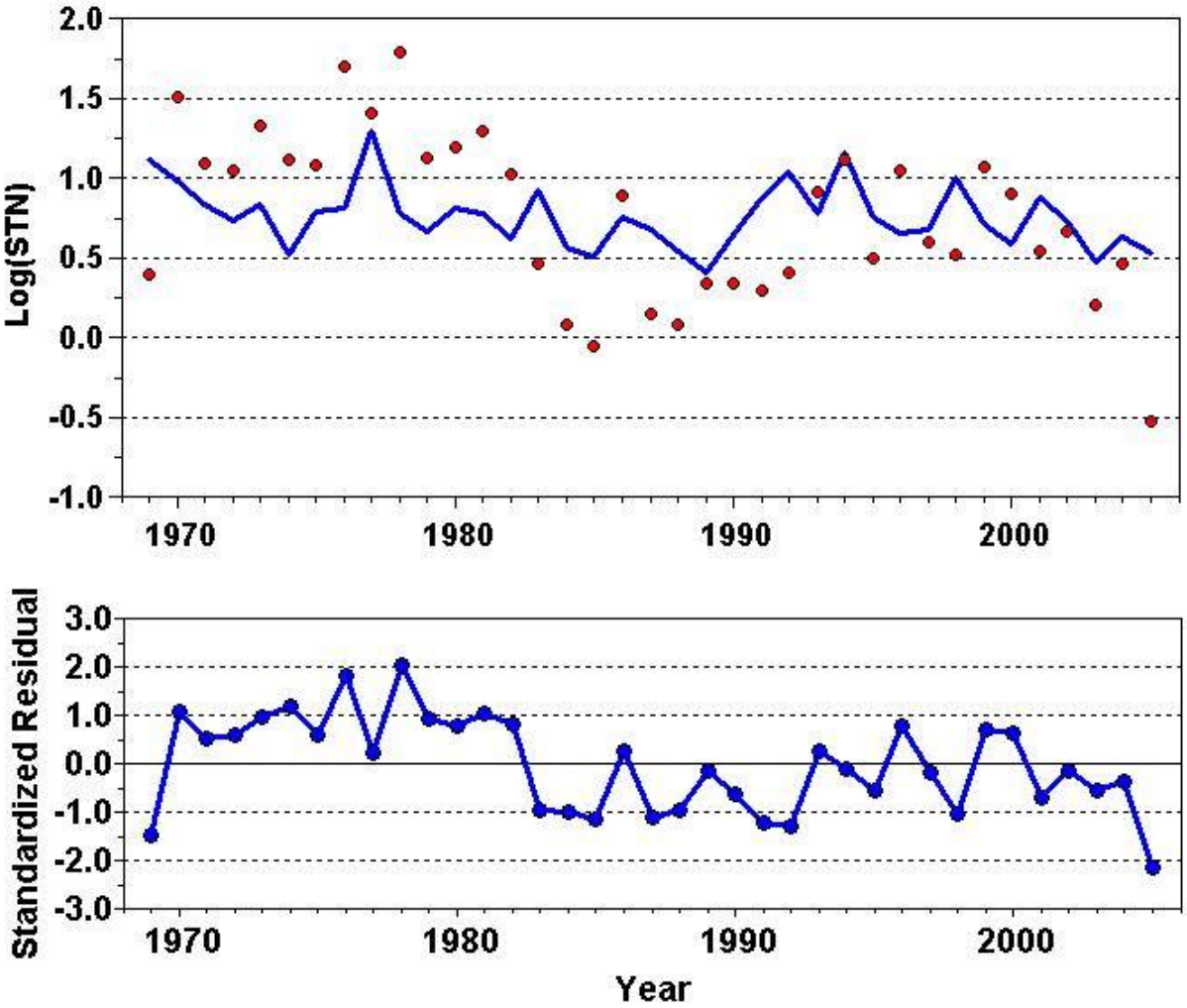

Figure 4.18 Observed (●) and expected (—) values of Log(STN) from the regression of Log(STN) values against total exports March to July, plotted against the calendar year (top panel), with the standardized residuals also plotted (bottom panel).

The simple regression model assuming that the mean of Log(STN) has one value before 1983 and another value from 1983 onwards accounts for 48.3% of the variation in the data. This is much more than the percentage accounted for by total exports, and is very highly significant ($t = -5.78$ with 35 df, $p < 0.0001$). Adding an export effect increases the percentage of the variation accounted for to 53.0%, which is approaching significance ($t = -1.73$ with 34 df, $p = 0.094$). Allowing the coefficient of total exports to change between 1982 and 1983 increases the variation accounted for to 56.2%, but this is not significant ($t = -1.56$ with 33 df, $p = 0.129$).

The possibility of correlated regression residuals was considered, but no evidence for this was obtained. The best model for the data therefore appears to be one for which Log(STN) has one mean value before 1983 and a different mean value from 1983

onwards. However, because the effect of total exports is approaching significance when added into the equation, I consider further the regression including an export effect. The estimated model is then

$$\text{Log(STN)} = 1.621 - 0.685(\text{Period2}) - 0.251(\text{TExp})$$

where Period2 is a 0-1 variable that equals 1 after 1982. This means that up to 1982 the model is

$$\text{Log(STN)} = 1.621 - 0.251(\text{Exports}),$$

then it changes to

$$\text{Log(STN)} = 0.936 - 0.251(\text{Exports}).$$

Figure 4.19 shows the observed and expected values of STN from this model, together with the standardized residuals. There are still patterns in the residuals. The expected values of Log(STN) seem to be too low in the 1980s and too high in the 1990s. Also the equation fails to account for the extremely low value of Log(STN) in 2005.

Conclusions

A simple regression of Log(STN) values against total exports from March to July is significant but it under-estimates the Log(STN) values up to the early 1980s and then over-estimates the values. There is an apparent shift in the mean of Log(STN) between 1982 and 1983. Allowing for a change in the mean, the effect of total exports is no longer quite significant, but the model including an export effect accounts for 53.0% of the variation in the data. When the observed and expected values of Log(STN) are plotted against years it is apparent that there are still patterns in the residuals, suggesting that there is a variable affecting the results that is not in the model. Also, the model does not account for the very low Log(STN) value in 2005.

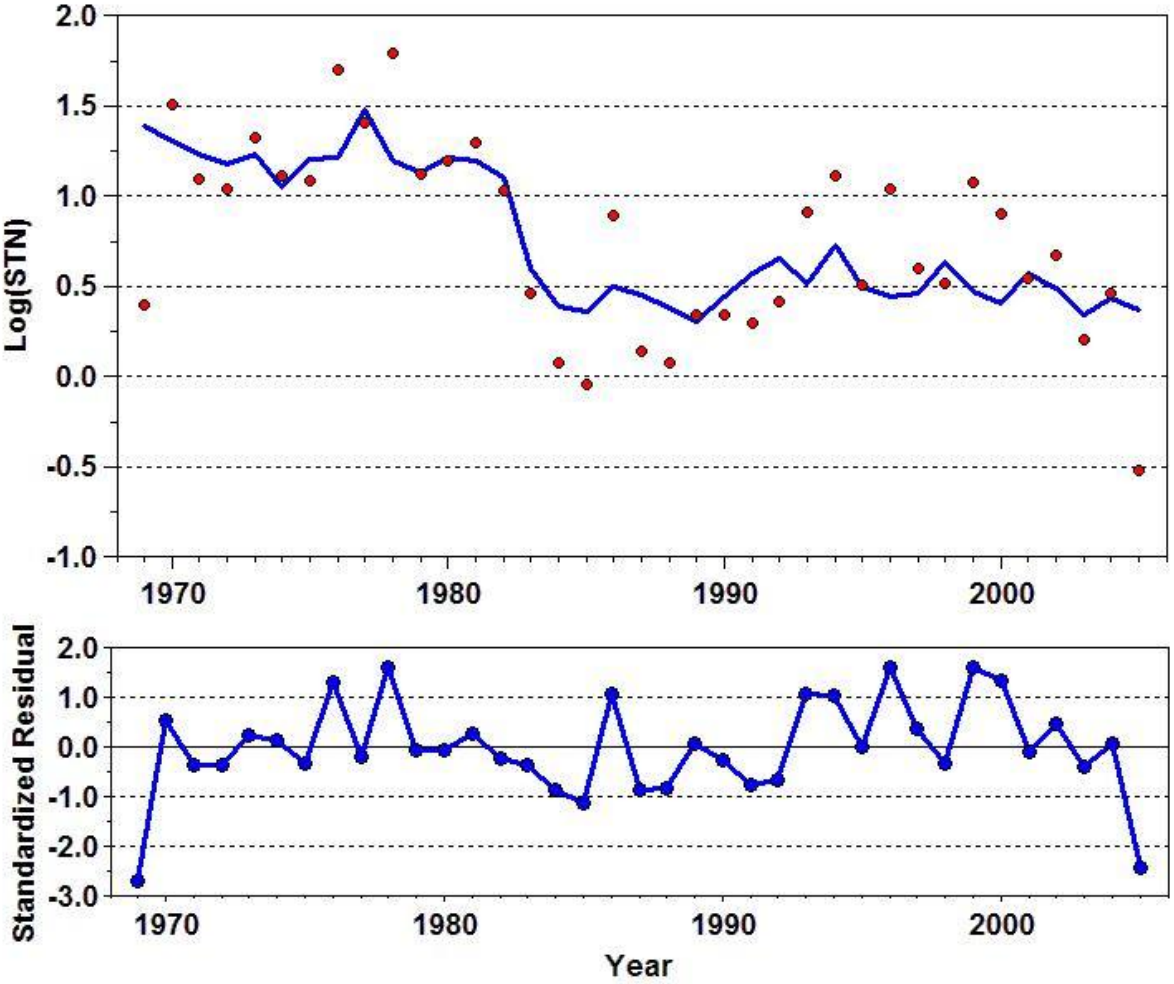

Figure 4.19 Observed (●) and expected (—) values of Log(STN) from the regression of Log(STN) values against total exports March to July, plotted against the calendar year (top panel), with the standardized residuals also plotted (bottom panel).

5. Analyses Made by B.J. Miller

(a) Delta Smelt Abundance Estimated Using the Spring Kodiak Trawl Data

The estimation of delta smelt abundances in different parts of the Sacramento-San Joaquin Delta based on Kodiak trawl sampling in the spring (January to March) is important for several of the analyses carried out by B.J. Miller. The approach used is standard, based on stratified sampling equations. The Delta was divided into 14 sampling areas (Napa River, Carquinez Strait, Suisun Bay, Suisun Marsh, Chipps Island, the lower Sacramento River, Cache Slough, the upper Sacramento River, the lower San Joaquin River, near Franks Tract, the east southeast Delta, the east central Delta, the southeast Delta, and the Sacramento Ship Channel) , and the number of delta smelt in an area in a sample month was estimated by the average catch per m^3 of water sampled in the area, multiplied by the total volume of water in the area (Miller, 2005a).

Calculation of CPUE and Abundance Estimates

The first stage in calculating abundance estimates involved calculating the CPUE (the catch of delta smelt per m^3 of water sampled). Data are available for 928 individual Kodiak trawls, which provide 238 values of CPUE, with the number of tows in individual sampling areas varying from 0 to 37 in a month. These data are available in a spreadsheet called Kodiak_Population_Data.xls provided by A.S. Britton and dated January 12, 2006. This spreadsheet also contains the calculation of the CPUE values and the population estimates for each area in each sample month. Starting with the data from individual tows I was able to verify that the CPUE values in the spreadsheet are correct.

To estimate the abundance in an area the CPUE values must be multiplied by the volume of water in the area. Table 5.1 below shows the volumes as provided by B.J. Miller in a file called consolidated_area_volume.xls and dated January 20 2006. The first column in the body of the table provides estimates of the total volume of water in each of the areas in acre-feet. The second column shows these volumes converted to cubic meters using the conversion factor of one acre feet to 1235 m^3. A more exact conversion factor is 1233.482, but given the uncertainty associated with the acre-feet values this does not seem a serious issue. The final two columns of the table show the estimated volumes above 12 feet, and the estimated volumes above 12 feet with the water in the Suisun Marsh tributaries excluded.

An assumption made by Miller (2005a) in his calculations is that most delta smelt occur within 12 feet of the surface, and that the catch in the Kodiak trawl (which only samples the top six feet) represents the delta smelt down to a depth of 12 feet. He notes the need for more information about the distribution of delta smelt in the water column when an assumption like this is made. He also assumed that there are no delta smelt in the Suisun Marsh tributaries. Therefore the volumes used to multiply the CPUE values in different areas are those shown in the last column of Table 5.1.

Table 5.1 Estimated volumes of water in different sampling areas in the Sacramento-San Joaquin Delta, as provided by B.J. Miller. The methods used to generate these estimates are described by Miller (2005b).

Area	Total Estimated Volume Acre feet	m^3	Above 12'[a] m^3	Reduced[b] m^3
San Pablo Bay	316220	390531700	262153386	262153386
Napa River	48130	59440550	37727501	37727501
Carquinez Strait	212810	262820350	75818379	75818379
Suisun Bay	293380	362324300	214010561	214010561
Suisun Marsh	75470	93205450	58068944	20503090
Chipps Island	101670	125562450	62968058	62968058
Lower Sacramento River	151030	186522050	98539514	98539514
Cache Slough	34590	42718650	22327887	22327887
Upper Sacramento River	45400	56069000	41285667	41285667
Lower San Joaquin River	108720	134269200	69675332	69675332
Near Franks Tract	196780	243023300	145660594	145660594
East Southeast Delta	76540	94526900	48708259	48708259
East Central Delta	55610	68678350	45717438	45717438
Southeast Delta	72320	89315200	58719519	58719519
Sacramento Ship Channel	28618	35343230	21148118	21148118

[a]The volume above 12 feet was calculated on the assumption that most delta smelt are found within this volume.
[b]The volume for Suisun March is reduced by removing the volume of tributaries, on the assumption that delta smelt are not found in these tributaries.

Multiplying the CPUE values by the volumes shown in the last column of Table 5.1 gives the estimated delta smelt numbers shown in Table C3 in Appendix C. These are the same as the values in Table 2 of Miller (2005a), except that in that table there are some zeros instead of blanks when there was no sampling in an area, particularly for the Sacramento Ship Channel. In Table C3 the blanks all indicate the absence of sampling.

Conclusions

The estimated abundances provided by Miller (2005b) are correct, subject to the assumptions made, and some small rounding errors associated with the calculations of the volumes used. Given the assumptions that have to be made, that the sampling was not designed to provide absolute population estimates, and that there is some vagueness about the sampling design (Miller, 2005a, p. 4), it is clear that the estimates of population numbers have to be regarded as initial approximations. If more information becomes available in the future about the distribution of delta smelt in the water column, the sampling efficiency of the Kodiak trawl, and the extent to which the sampling sites truly represent the areas that they are in then perhaps the estimates will need to be modified. There can be more confidence in the estimates as indices of relative abundance, rather than as estimates of absolute abundance. However, indices serve as well as absolute abundance estimates for many analyses of trend and change.

The use of data from sampling of the Sacramento Ship Channel is problematic. This area was sometimes covered in supplemental samples after regular sampling was completed, with surprisingly high delta smelt densities being found. The problem is that apparently supplemental samples were aimed at areas where delta smelt were expected to be found, i.e. the sampling may be biased. It would clearly be better if the Sacramento Ship Channel is included in the regular stratified sampling program in future. In the meantime, the supplemental samples, even if somewhat biased, are the best indication available of the delta smelt densities in the Ship Channel in spring for 2003 to 2005.

(b) Summer Overlap of Delta Smelt and Prey and the FMWT Index

The idea behind this analysis is that delta smelt numbers may be limited by the abundance of food in the summer. If this is the case, then high delta smelt numbers at the end of a year require that (i) the numbers are high in the summer, and (ii) that the delta smelt are mostly in areas where there is an abundance of food. Based on this idea, Miller *et al*. (2005) constructed a summer delta smelt-prey overlap index, and related this to the Fall Midwater Trawl (FMWT) index of the abundance of delta smelt later in the year. A highly significant relationship was found, and Miller *et al*. concluded that the major factor in the decline of delta smelt in recent years has been the absence of food.

Calculation of a Delta Smelt/Prey Overlap Index

Miller *et al*. (2005) identified the zooplankton species *Eurytemora affinis* and *Pseudodiaptomus forbesi* as the principal prey for delta smelt, with *Acartiella sinensis* and *Tortanus species* as potential prey as well. Their delta smelt prey overlap index was therefore calculated using just the first two of these species, and also using all four species.

To calculate an overlap index it was necessary to divide the Sacramento-San Joaquin Delta into sampling areas. The areas defined by Miller (2005b) were used for this purpose, where these are the same as the areas used for analysis (a) above. However, no zooplankton samples were taken in the Napa River, Cache Slough, Upper Sacramento River, Sacramento Ship Channel and East Central Delta areas. Therefore these areas could not be included in the calculations.

Having defined the regions to be used, the catch per unit effort (CPUE, i.e., the catch per tow) can be calculated for delta smelt and each of the zooplankton prey species, for each of the regions, for the years 1985 to 2004. The calculation of the CPUE values was restricted to July because this is the only summer month when delta smelt have usually been sampled since 1985. Even so, the values for 1988 could not be used because there was no delta smelt sampling in July of that year.

The zooplankton data come from a data set called the CB-Matrix, where CB stands for the Clarke-Bumpus net, which tends to capture large zooplankton. The full CB-Matrix

contains data on the catches in individual tows for a large number of zooplankton species but does not contain information on where the tows were taken in terms of the regions used for the calculation of the overlap index. For that reason I reproduced the Miller *et al*. (2005) overlap calculations using data in the file 1985-2005_CB_Matrix.xls that was provided to me by A.S. Britton on December 20, 2005. One sheet in this file gives the densities of the four zooplankton prey species from July samples only, with the sampling regions identified. Using these data I was able to verify the average zooplankton CPUE values for different regions in different years as used by Miller *et al*. (2005). The prey density data used for the overlap analysis therefore appear to be correct.

For delta smelt densities Miller *et al*. (2005) used CPUE values from July Summer Townet (STN) sampling. I used data included in the file tns_effort.xls provided by A.S. Britton on January 18, 2006 to verify the average CPUE values for delta smelt in different regions in different years that were used by Miller *et al*. for the overlap index values. I found their calculated delta smelt CPUE values to be correct.

The final stage in the determination of the overlap index for a year involves calculating for each area of the Sacramento-San Joaquin Delta the product

Overlap = (Prey Density)x(Delta Smelt Density)x(Volume of Water),

where the volume of water is the volume for the whole of the area being considered, as provided in the first column of volumes in Table 5.1, above. These quantities are then added up over all of the areas. The reason for multiplying by the volume is that the delta smelt density times the volume is expected to be approximately proportional to the total number of adult delta smelt in the region, while multiplying by the prey density modifies this population size index to take into account the abundance of prey.

Appendix Table C4 shows the estimated delta smelt numbers (i.e., the estimated densities times volumes) for 1985 to 2004 for the areas sampled in the STN. Table C5 shows the estimated prey densities for the same years for the areas sampled for zooplankton, and Table C6 shows the final overlap values for the four prey. In Table C4, blanks indicate that no sampling occurred, so that there is no information about the numbers of delta smelt in those areas and years. Similarly in Table C5 blanks indicate no sampling, so that there is no information about zooplankton densities in those areas and years. Finally, in Tables B4 there are blanks because of missing information about either the delta smelt number or the zooplankton density.

Tables 1 and 3 of Miller *et al*. (2005) give overlap values for all four prey types combined, and for just *Eurytemora affinis* and *Pseudodiaptomus forbesi*. The values in those tables are not in agreement with the values shown in Table C5. However, the values in Table C5 do agree with the values in the spreadsheets for the overlap calculations provided by B.J. Miller, except for some differences in the water volumes used for different areas. The water volumes used here are as shown in Table 5.1.

Relating the FMWT Index to the Overlap Index

Miller *et al*. (2005) described regression equations relating the FMWT abundance index to overlap indices. They first regressed the FMWT against the overlap index based on *E. affinis* and *P. forbesi*, and then against the overlap index based on all four prey types. The data for these analyses are provided in Table 5.2. These data are not quite the same as used by Miller *et al*. (2005) because of the revised water volumes being used here.

Table 5.2 FMWT index values and corresponding overlap index values for the four individual prey types, *E. affinis* plus *P. forbesi*, and all four prey types together. All overlap indices are based on the estimates provided in Table C6 but divided by 10,000 for regression calculations. The number of sampled areas with the information needed to calculate overlap values is also shown, out of a maximum of 15.

Year	Sampled Areas	FMWT	*E. affinis*	*P. forbesi*	*A. sinensis*	*T. species*	Two Prey Overlap	Four Prey Overlap
1985	8	110	30.87	0.00	0.00	0.00	30.87	30.87
1986	8	212	247.98	0.00	0.00	0.00	247.98	247.98
1987	8	280	134.41	0.00	0.00	0.00	134.41	134.41
1989	8	366	1.95	204.00	0.00	0.00	205.95	205.95
1990	8	364	0.00	328.52	0.00	0.00	328.52	328.52
1991	8	689	2.27	842.09	0.00	0.00	844.36	844.36
1992	8	156	0.01	121.82	0.00	0.00	121.84	121.84
1993	9	1,078	0.26	664.21	0.00	0.00	664.47	664.47
1994	7	102	0.00	301.73	423.50	0.76	301.73	725.99
1995	6	899	0.02	270.50	1.60	5.55	270.51	277.67
1996	8	127	0.00	207.72	35.25	10.55	207.72	253.52
1997	7	303	0.00	112.58	17.04	0.76	112.58	130.39
1998	10	420	0.00	134.73	2.83	24.45	134.73	162.00
1999	9	864	1.03	710.28	0.00	5.86	711.31	717.17
2000	9	756	0.21	402.70	1.31	12.37	402.91	416.59
2001	8	603	0.00	235.75	69.00	5.07	235.75	309.81
2002	9	139	0.11	72.75	16.00	1.65	72.86	90.51
2003	9	210	0.00	56.46	9.73	0.87	56.46	67.06
2004	9	74	0.00	4.77	6.72	0.71	4.77	12.20

The overlap values for individual years shown in Table 5.2 are based on samples of from 6 to 10 of the 15 areas in the Sacramento-San Joaquin Delta. Therefore these values are all underestimates of the true delta smelt-prey overlap in the delta unless there was no overlap at all in the areas that were not sampled for both delta smelt and zooplankton. The bias is also probably not constant over the years because of the variation in the number of areas covered in different years. If anything, the biases caused by incomplete sampling will presumably result in hiding some of the true relationship between the overlap indices and the FMWT index in the same year.

Regressing the FMWT index against the overlap index based on *E. affinis* and *P. forbesi* for the same year using the data in Table 5.2 yields the fitted equation

$$FMWT = 141.07 + 0.9964(Overlap),$$

where the coefficient of the overlap index has an estimated standard error of 0.2098. The equation accounts for 57% of the variation in the FMWT values, and the coefficient of the overlap index is highly significant ($t = 4.75$ with 17 df, $p = 0.0002$). Figure 5.1 shows the observed and fitted values for the FMWT index. The results from this analysis are slightly less significant than the results reported by Miller *et al*. (2005).

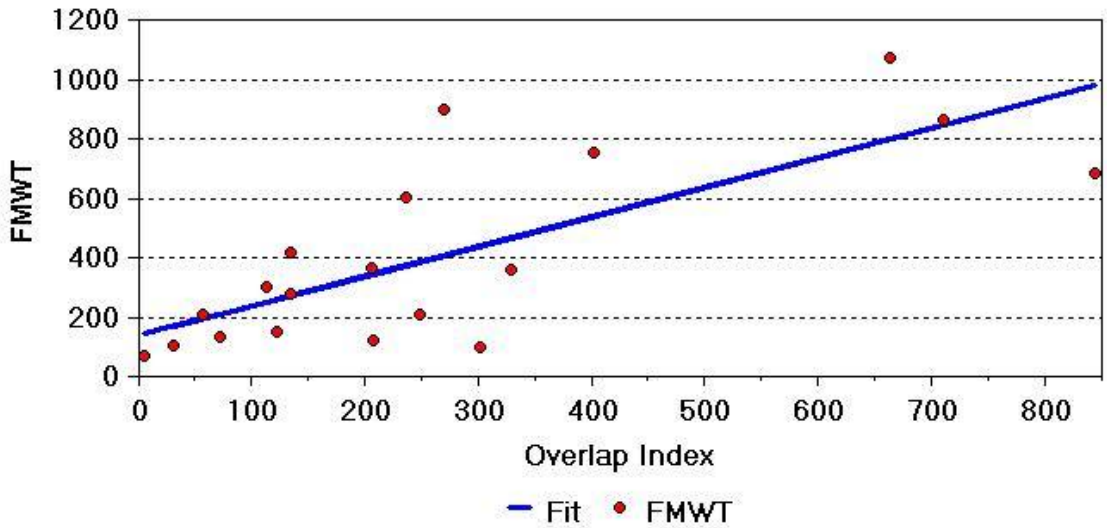

Figure 5.1 Regression of the FMWT abundance index against the summer delta smelt-prey overlap index calculated using *E. affinis* and *P. forbesi*.

If all four zooplankton prey are used to calculate the overlap index then the regression equation obtained is

$$FMWT = 182.58 + 0.7460(Overlap),$$

where the coefficient of the overlap index has an estimated standard error of 0.2349. This equation only accounts for 37% of the variation in the FMWT abundance index, but the coefficient of the overlap index is still significant at the 1% level ($t = 3.18$ with 17 df, $p = 0.0055$). Figure 5.2 shows the observed and fitted values for the FMWT index. As was the case for the first regression, the results from this analysis are slightly less significant than the results reported by Miller *et al*. (2005).

The relatively low percentage of the variation accounted for by this equation is due mainly to the data for 1994 (FMWT = 102, Overlap Index = 726), where the high overlap index was due to the unusual abundance of *A. sinensis* in the lower Sacramento River. Miller *et al*. (2005) found that the fit was improved considerably by removing the 1994 data, but that cannot really be justified without some real reason for questioning the accuracy of the data for that year.

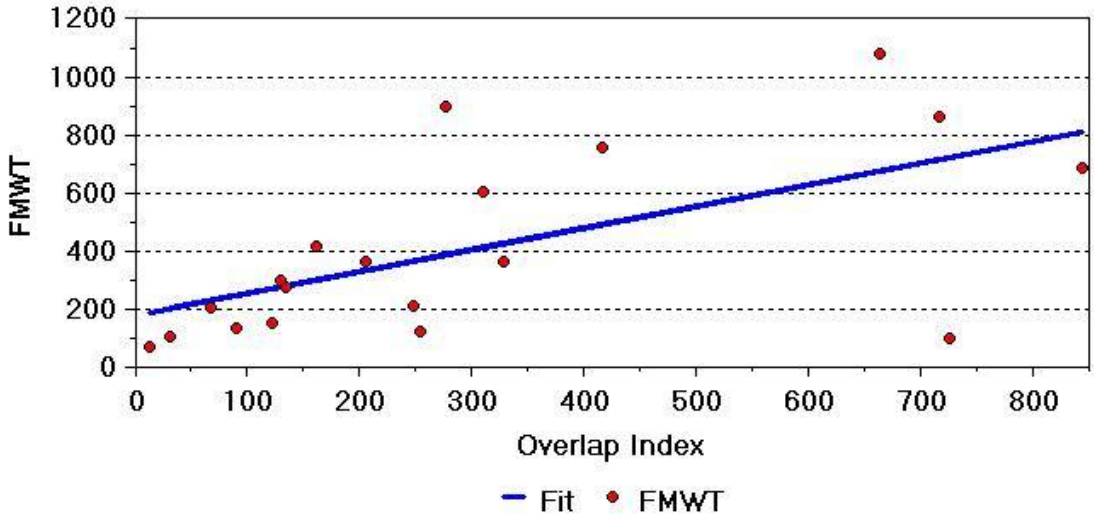

Figure 5.2 Regression of the FMWT abundance index against the summer delta smelt-prey overlap index calculated using all four prey.

Figures 5.1 and 5.2 suggest that the variance in the regression residuals may be increasing as the overlap index increases. Redoing the regressions using the logarithms of FMWT values overcomes this problem to some extent. The regressions are still significant, but slightly less significant than those using the FMWT values directly. The plots of observed and fitted values of the FMWT index against the year that are shown in Figure 5.3 indicate that the apparent increase in the variance of the residuals with an increase in the FMWT is actually due to the fact that the observed and fitted values of the FMWT agree fairly well for the times when the fitted values are low (1985-90 and 2002-04). However, between 1991 and 2001 the average value of the FMWT index was higher but the individual yearly values were extremely variable.

It is also notable that between 1990 and 1997 there is a pattern of alternating high and low values for the observed FMWT index, which the fitted regression models do not capture very well. One of the results of this is a fairly high negative correlation between the regression residual in successive years. For the two prey model this correlation between successive residuals is -0.40. Fitting a regression model with correlated residuals shows that this correlation is not significant at the 5% level ($t = -1.66$ with 16 df, $p = 0.116$). The estimated coefficient of the overlap index changes slightly from 0.996 to 0.966 with this model, but is still very highly significant ($t = 5.25$ with 16 df, $p = 0.0001$), so that the conclusions from the analysis do not change.

For the four prey model the correlation between successive residuals is -0.57. Fitting a regression model with correlated errors shows that this correlation is significant ($t = -2.67$ with 16 df, $p = 0.017$). With this model the coefficient of the overlap index changes from 0.746 to 0.819 and is very significant ($t = 4.89$ with 16 df, $p = 0.0002$). Therefore again allowing for correlated residuals does not change the conclusions from the analysis.

The oscillating values of the FMWT index seem difficult to account for, unless they are due to chance. They do suggest that between 1990 and 1997 some unmeasured variable was affecting the FMWT abundance index.

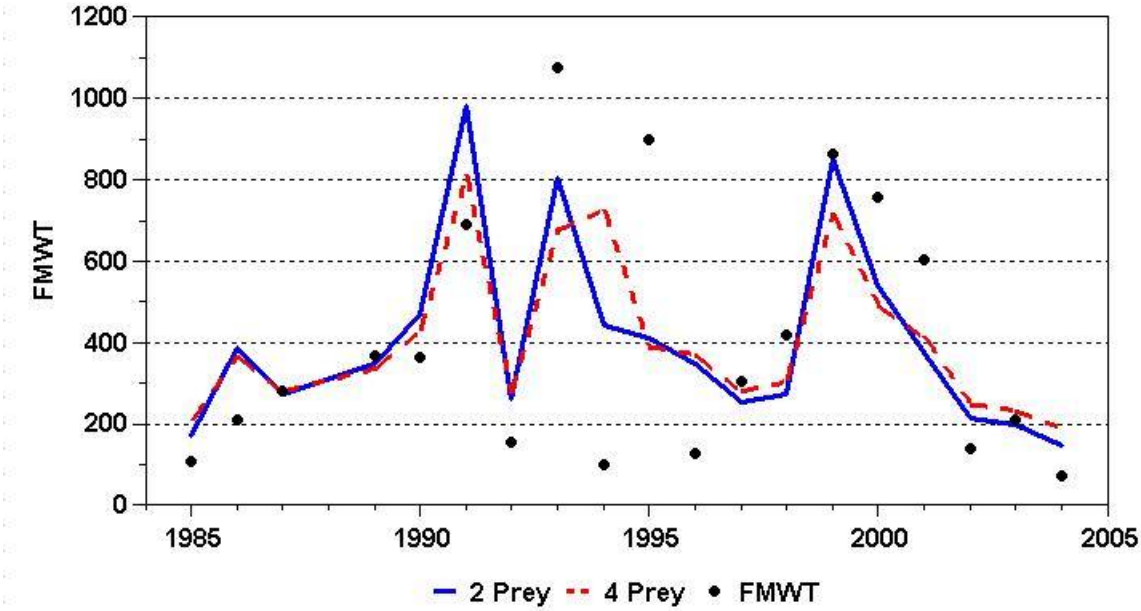

Figure 5.3 Observed values of the FMWT abundance index and the fitted values from the delta smelt overlap index regression based on two prey and four prey types, plotted against the year.

Some Extra Regressions

In this section some extra regressions are considered to supplement the ones considered by B.J. Miller. No allowance has been made for the apparent negative correlation between successive regression residuals with these extra regressions because it is not clear what might cause such a correlation, and if an allowance was made it should not change the fitted regression equations much.

Miller *et al*. (2005) considered regressions on the sum of the overlap values for on *E. affinis* and *P. forbesi* and also the sum of the overlap values for all four prey types. This assumes that an individual prey item has the same food value for all prey species. An alternative to this involves using the overlap values for the four individual zooplankton species shown in Table 5.2 as four separate variables in a regression. These variables have non-significant correlations (Table 5.3) so that in principle separate effects can be estimated.

When the overlap values for the four zooplankton species are included in the regression equation, 68% of the variation in the FMWT index is accounted for. The coefficient is very highly significant for *P. forbesi* ($t = 4.92$, $p = 0.0002$), but the coefficients are not significant for *E. affinis* ($t = 0.44$, $p = 0.664$), *A. sinensis* ($t = -1.64$, $p = 0.123$) or *T.*

species (t = 1.05, p = 0.313). When *E. affinis* is removed from the equation it still accounts for 68% of the variation in the FMWT index, with the coefficient of *P. forbesi* even more significant (t = 5.23, p = 0.0001), but the coefficients of *A. sinensis* (t = -1.76, p = 0.098) and *T. species* (t = 1.00, p = 0.334) are still insignificant. When *T. species* is removed from the equation it still accounts for 66% of the variation in the FMWT index. The significance of the coefficient of *P. forbesi* is only changed slightly (t = 5.27, p = 0.0001), and the coefficient of *A. sinensis* is still not significant at the 5% level (t = -1.85, p = 0.082), although it is approaching significance. The removal of *A. sinensis* from the equation results in a drop to 58% of the variation accounted for, with the coefficient of *P. forbesi* still being highly significant (t = 4.88, p = 0.0001).

Table 5.3 Correlations between delta smelt-prey overlap indices for four species of zooplankton. All of the estimated correlations are insignificant at the 5% level.

	E. affinis	*P. forbesi*	*A. sinensis*	*T. species*
E. affinis	1.00	-0.35	-0.12	-0.21
P. forbesi	-0.35	1.00	0.03	0.03
A. sinensis	-0.12	0.03	1.00	-0.08
T. species	-0.21	0.03	-0.08	1.00

The final outcome of this fitting process is an equation using the overlap values for one zooplankton species that accounts for almost the same amount of variation as Miller *et al.*'s (1995) equation using the sum of the overlap values for two zooplankton species. There is therefore no improvement in the fit obtained by considering the individual species.

I also considered whether the estimated abundance of the four zooplankton species in summer can be used to predict the FMWT abundance later in the year, where the abundance of a zooplankton species in an area is estimated by multiplying the CPUE by the water volume. The sum of these values over sampled areas then gives the estimated total abundance. When I related the FMWT index to the four zooplankton population sizes in one regression the equation accounted for 34% of the variation in the FMWT the regression coefficients were not significantly different from zero. Removing insignificant variables one by one resulted in an equation relating the FMWT index just to the *P. forbesi* abundance. This accounts for 24% of the variation in the FMWT index and the coefficient of *P. forbesi* abundance is significant at the 5% level (t = 2.32, p = 0.033).

Clearly the abundance of the zooplankton species does not predict the FMWT index as well as the overlap indices because using the overlap index for *P. forbesi* accounts for 58% of the variation in the FMWT index. It is also possible that the predictive ability of the *P. forbesi* abundance just arises because it is correlated to some extent with the *P. forbesi* overlap index (r = 0.53), i.e. the abundance is just representing the overlap index to a limited extent.

Suppose that the survival rate (S) of delta smelt in an area between the summer and the fall is approximately linearly related to the summer zooplankton abundance (Z), so that

$$S = a + bZ.$$

where a and b are constants. Then the fall population size in area i will be given by

$$N_{iF} = (a + bZ_i)N_{iS},$$

where N_{iF} is the fall population size, N_{iS} is the summer population size, and Z_i is the zooplankton abundance in the area. The total fall population size would then be obtained by adding over the areas, i.e.

$$N_F = \sum N_{iF} = \sum (a + bZ_i)N_{iS} = a \sum N_{iS} + b \sum Z_i N_{iS}.$$

Thus the fall population would be a constant times the summer population, plus another constant times the Miller et al. (2005) delta smelt-prey overlap index. This suggests that rather than relating the FMWT just to the overlap index, it should be related to the overlap index and the estimated delta smelt population in the summer (STN delta smelt CPUE values times the water volumes, summed over all of the sampled areas). Also, the regression equation should not contain a constant term.

This idea was investigated. It turns out that if all four zooplankton species are considered individually it is still only the overlap index for *P. forbesi* that is significantly related to the FMWT index. The equation

$$\text{FMWT} = 0.0418(\text{STN}) + 0.975(\text{Overlap})$$

accounts for 49% of the variation in the FMWT index, where STN is the estimated delta smelt abundance from the summer townet sampling, and Overlap is the delta smelt-*P. forbesi* overlap index. The coefficient of overlap is highly significant ($t = 3.77$, $p = 0.002$), but the coefficient of STN is not significantly different from zero ($t = 1.58$, $p = 0.133$). Also, the simple regression of FMWT against Overlap with a constant term accounts for 58% of the variation in the FMWT. Therefore, this model is not an improvement on the simple regression model.

Conclusions

There is a clear, very highly significant correlation between the FMWT abundance index and the Miller *et al*. (2005) overlap index calculated using either the sum of the *E. affinis* and *P. forbesi* densities, or the *P. forbesi* density alone. A less significant result is obtained if the overlap index is calculated using the densities of *E. affinis*, *P. forbesi*, *A. sinensis* and *T. species*, because this hides the effect of *P. forbesi* to some extent. There is an apparent negative correlation between successive regression residuals, but making an allowance for this does no change the conclusions.

The evidence for a relationship is clear, but whether this is a causal relationship or an association related to some other factor is a matter of judgment. In this respect it is relevant that it is the co-occurrence of delta smelt and prey in specific areas that is causing the relationship rather than just the abundance of prey overall. This is shown by the fact that a regression of the FMWT index against the *P. forbesi* abundance only 24% of the variation in the FMWT index, which is less than half of what is accounted for with a regression of the FMWT index against the *P. forbesi* overlap index.

Certainly, the delta smelt-prey overlap effect should be investigated further in the future. Particularly, it would be interesting to include data collected before 1985. The prey may not be the same but it would be helpful to see whether an overlap effect exists with the prey used in those earlier years.

Some improvements in the analysis may also be possible in the future. This could include making some allowance for some areas not being sampled every year, taking into account minimum and maximum prey densities for effects to occur (Miller *et al*., 2005), and a clearer model for the relationship between prey density, delta smelt survival from summer to the fall, and the delta smelt abundance in the fall. As shown above, a simple model where the summer to fall survival of delta smelt is linearly related to the prey density implies that the FMWT index should be linearly related to the summer delta smelt abundance and the overlap index, without a constant term. However, this model does not fit the data as well as a linear relationship between the FMWT index and the overlap index, with a constant term. It is not clear why this is the case, but obviously the underlying model for the analysis could be considered further.

(c) Delta Smelt Adult Salvage Related to Abundance East of Franks Tract

This analysis involved relating the estimated total adult salvage at the state and federal export facilities to the estimated number of delta smelt east of Franks Tract from the Spring Kodiak Trawl, and other variables. The estimated number of delta smelt east of Franks Tract was found to be a good predictor of the salvage numbers by B.J. Miller, while the other variables considered did not have significant effects after the effects of this variable were allowed for.

Regression Analyses

The data for regression calculations are given in a spreadsheet named Adult_Salvage_and_East_of_Franks.xls, provided by B.J. Miller and dated January 12, 2006. The data used here to repeat the calculations are shown in Table 5.4. These differ slightly from the data used by B.J. Miller for two reasons. First, the file Smelt_Salvage_Length.xls dated December 31, 2005, which was provided by B.J. Miller with separate counts for juvenile and adult salvage of delta smelt had three cases of unclassified salvage in 2005. These were on February 15 (salvage 6), February 16 (salvage 18), and May 11 (salvage 3). According to B.J. Miller the salvage on February

15 and 16 was of adults while the salvage on May 11 was of juveniles. The adult salvage used by B.J. Miller for his calculations was 329 for February 2005, which did not include the unclassified adults. Here the salvage number used is 329 + 6 + 18 = 353, which includes the unclassified adults. The other difference between the data used by B.J. Miller and the data used here is that here the adult salvage for May 2005 is not used because no Kodiak trawls were made near Franks Tract and east of Franks Tract in that month.

The variables shown in Table 5.4 are quite highly correlated, as shown in Table 5.5. Plots of each of the variables against the others are shown in Figure 5.4. There are more or less linear relationships between the delta smelt abundance near Franks Tract and east of Franks Tract (r = 0.632), salvage and the abundance east of Franks Tract (r = 0.850), and salvage and the delta smelt abundance near Franks Tract (r = 0.588). There are also approximately linear relationships between the delta smelt abundance east of Franks Tract and exports (r = 0.551), and the delta smelt abundance near Franks Tract and exports (r = 0.427), with the delta smelt abundances tending to increase with the level of exports. The relationship between salvage and exports is also apparently strong (r = 0.616), but seems clearly non-linear, with no salvage until export levels become quite high, and quite variable levels of salvage with these high levels of exports.

B.J. Miller used linear regression analyses to examine the relationship between the adult salvage and the other variables. His results are very similar to those that are given here, except as noted below, although the data are not quite the same. The regressions considered were as follows, where EFT denotes east of Franks Tract and NFT denotes near Franks Tract.

$$\text{Salvage} = -541.3 + 0.0765(\text{EFT}) + 0.1047(\text{Exports})$$

The variation accounted for is 75.3%. The coefficient of EFT significant at the 0.1% level, the coefficient of Exports not significant at the 5% level.

$$\text{Salvage} = -1220.9 + 0.0069(\text{NFT}) + 0.2206(\text{Exports})$$

The variation accounted for is 50.8%. Neither coefficient is significant at the 5% level.

$$\text{Salvage} = -562.0 + 0.0731(\text{EFT}) + 0.0010(\text{NFT}) + 0.1015(\text{Exports})$$

The variation accounted for is 75.5%. The coefficient of EFT is significant at the 1% level, the other coefficients are not significant at the 5% level.

$$\text{Salvage} = -1139.9 + 0.0074(\text{NFT}+\text{EFT}) + 0.1959(\text{Exports})$$

The variation accounted for is 55.2%. The coefficient of the sum of NFT and EFT is significant at the 5% level, the coefficient of exports is not significant at the 5% level.

$$\text{Salvage} = 163.7 + 0.0887(\text{EFT})$$

The variation accounted for is 72.2%. The coefficient of EFT is extremely significant (p = 0.0003).

$$\text{Exports} = 6533.5 + 0.0985(\text{EFT}) + 0.0046(\text{NFT})$$

The variation accounted for is 31.4%. Neither coefficient is significant at the 5% level. Note that this equation is very different from the equation provided by B.J. Miller for reasons that are unclear.

Table 5.4 Variables used in the analysis of the relationship between total adult salvage at the state and federal export facilities (Salvage) and other variables. The variable East of Franks Tract is the estimated number from the Spring Kodiak Trawl data shown in Table C3 (the estimates for East SE Delta + East Central Delta + SE Delta). The variable Near Franks Tract is the estimate given in Table C3 for this location. Total Exports are in acre feet.

Year	Month	East Franks Tract	Near Franks Tract	Total Exports	Salvage
2002	Jan	30433	152218	10611	5231
2002	Feb	0	197703	8581	280
2002	Mar	19640	23852	8078	225
2003	Feb	10658	26937	10658	1491
2003	Mar	10623	9747	10571	483
2003	Apr	0	82916	4478	36
2003	May	1434	0	2448	0
2004	Jan	58152	268331	11187	4594
2004	Feb	16634	265574	10376	1161
2004	Mar	18363	138916	11029	2267
2004	Apr	0	95568	4098	0
2004	May	0	12786	1714	0
2005	Jan	4958	52240	11990	1647
2005	Feb	0	0	8867	353[a]
2005	Mar	0	0	6988	0
2005	Apr	0	0	5868	0
2005	May			3085	0[b]

aThe value used by B.J. Miller was 329 because 24 adult delta smelt salvaged on February 15 and 16 were not recorded as juveniles or adults.

[b]This observation was used by B.J. Miller assuming zero abundance for East and Near Franks Tract. It is not used here because Kodiak trawls were not carried out in these areas in May 2005.

$$\text{NFT+1} = 2576.9 + 0.0589(\text{NFT}) + 0.2096(\text{Exports})$$

Here NFT+1 indicates the estimated abundance near Franks Tract in the following month. The variation accounted for is 55.5%. The coefficient of NFT is significant at the 1% level, the coefficient of Exports is not significant at the 5% level. It appears that the abundance near Franks Tract in one month can be predicted from the number in the previous month to some extent.

Table 5.5 Correlations (r) between the variables shown in Table 5.4.

	EFT[a]	NFT[b]	Exports	Salvage
EFT	1.000	0.632**	0.551*	0.850***
NFT	0.632**	1.000	0.427	0.588*
Exports	0.551*	0.427	1.000	0.616*
Salvage	0.850***	0.588*	0.616*	1.000

[a]East of Franks Tract.
[b]Near Franks Tract.
*Significant at the 5% level, **significant at the 1% level, ***significant at the 0.1% level.

In terms of predicting salvage the equation just including EFT seems clearly best, with 72.2% of the variation in Salvage accounted for. The observed and fitted values of salvage for this equation are shown in Figure 5.5. The assumptions for fitting the regression seem reasonable. An interesting question with this equation is the extent to which the non-linear relationship between salvage and exports that is shown in Figure 5.4 is accounted for. This is indicated by Figure 5.6, which shows the standardized residuals (the observed salvage minus the fitted salvage divided by the estimated standard deviation of regression errors) from the regression, plotted against exports. With low exports there is low salvage. The standardized residuals are all low for these cases, indicating that the regression equation predicts that this will occur. For exports above 6000 the residuals are positive and negative, with no very obvious pattern. Hence it appears that once the effect of the variable EFT is allowed for there is no clear relationship between salvage and exports.

Finally, Figure 5.7 shows the observed salvage values and the fitted values from the regression equation plotted against the observation time. The fit seems reasonable and the residuals from the regression appear to be random.

Conclusions

There are some differences between the data used here and that used by B.J. Miller, and one case where the regression equation found here is quite different from the one given by B.J. Miller. Nevertheless the final conclusion is essentially the same. It appears that the estimated abundance of delta smelt east of Franks Tract from spring Kodiak Trawl sampling is highly correlated with the total salvage at the state and federal export facilities, and that once the effects of this variable are allowed for, the other variables considered are not clearly related to salvage.

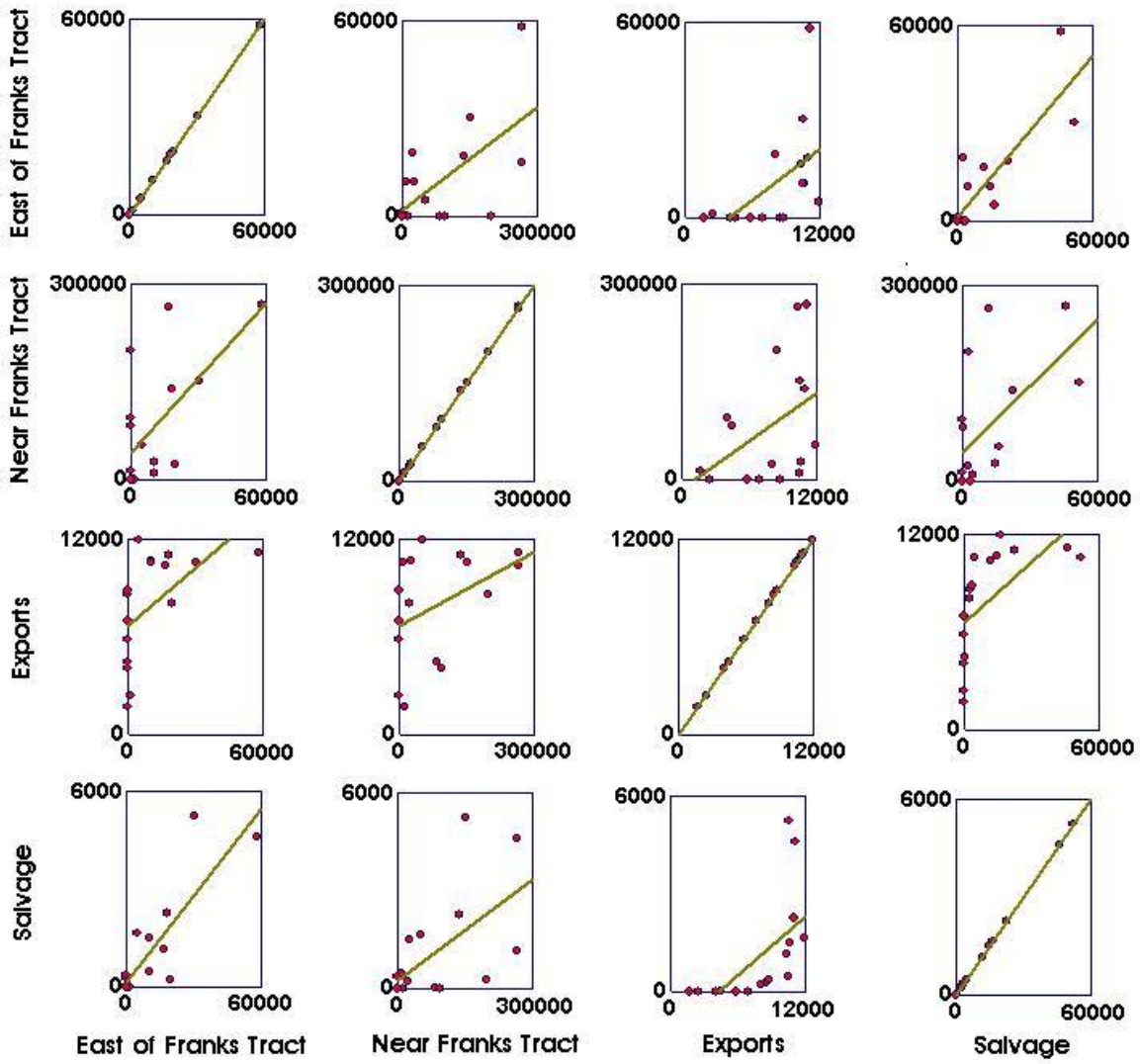

Figure 5.4 Variables from Table 5.4 plotted against each other. Each row gives a variable plotted against itself and the other variables. Each column gives plots of the variables against one variable.

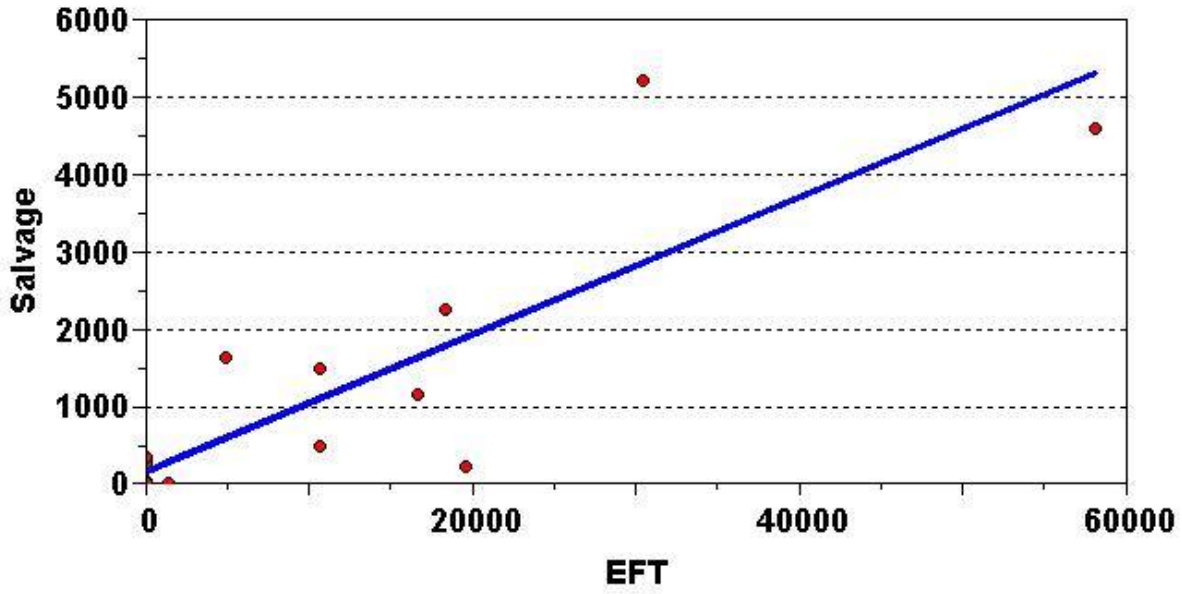

Figure 5.5 Observed (●) and expected (—) adult delta smelt salvage from the fitted regression of estimated adult salvage again the estimated abundance of delta smelt east of Franks Tract, Salvage = 163.7 + 0.0887(EFT).

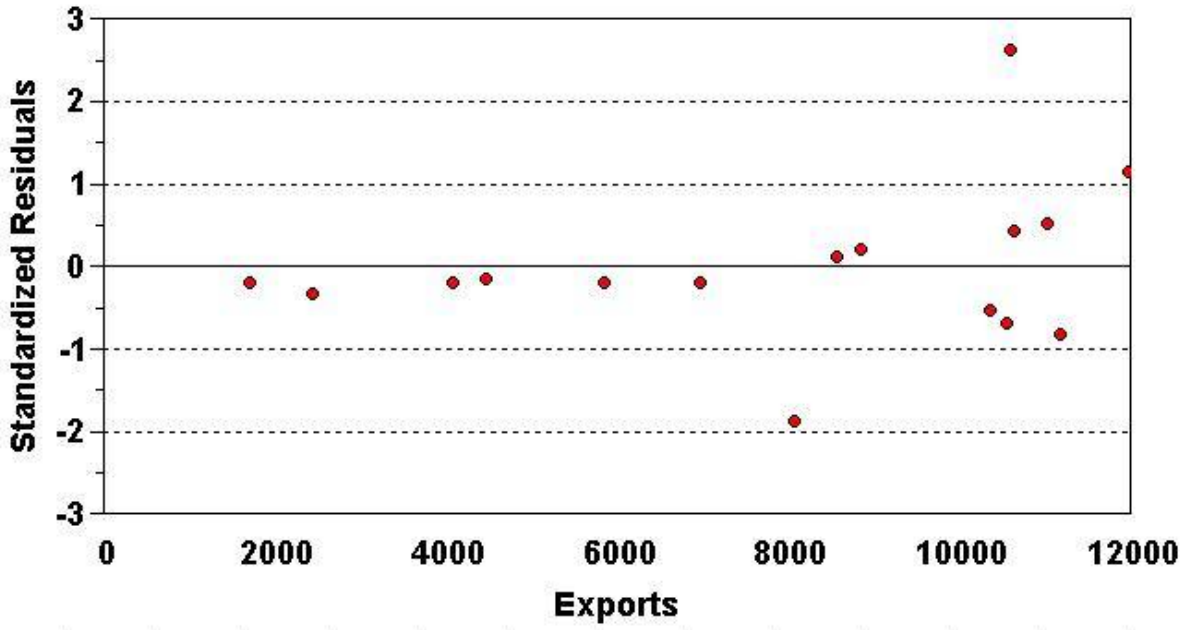

Figure 5.6 Standardized residuals from the regression of estimated adult salvage numbers against the estimated numbers east of Franks Tract (EFT).

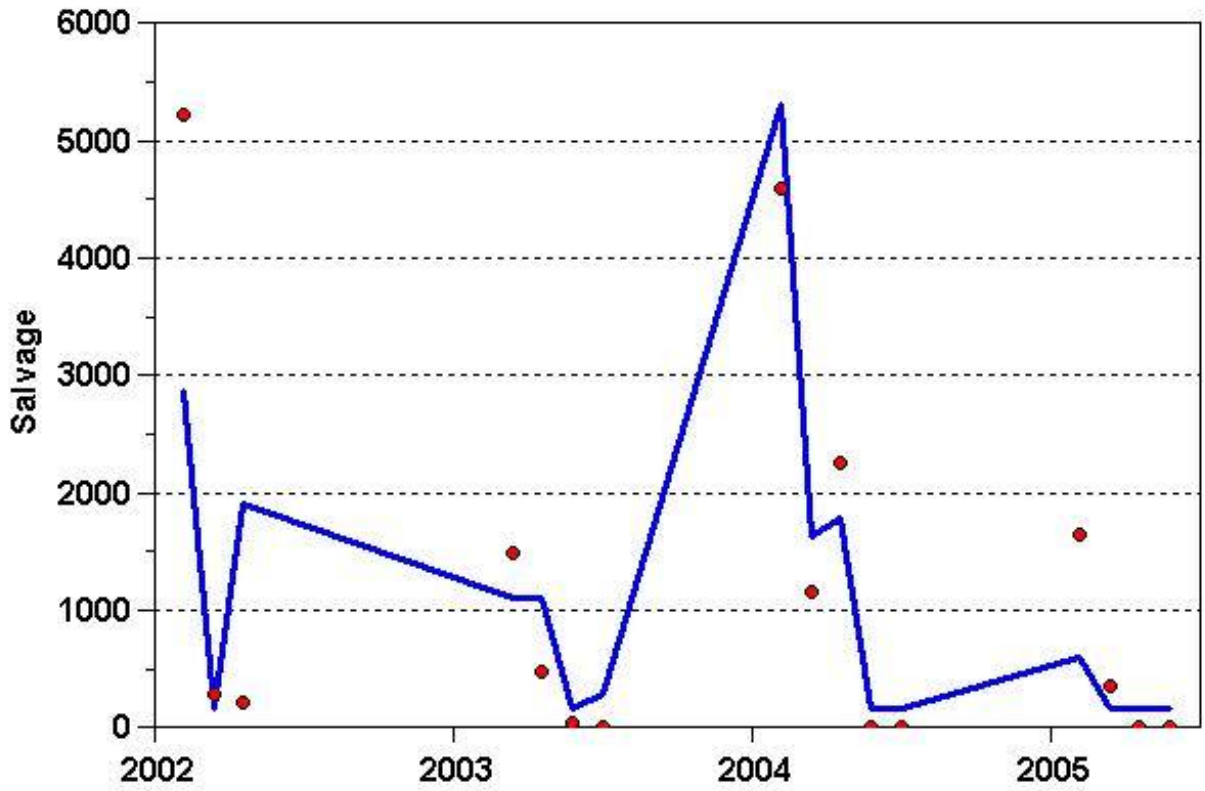

Figure 5.7 Observed (●) and expected (—) salvage based on the regression of salvage against the estimated numbers east of Franks Tract (EFT).

(d) Adult Entrainment at the Banks and Tracy Pumping Stations

This analysis was carried out by Miller (2005c) to estimate the numbers of delta smelt adults that were entrained at the state and federal pumping stations as a percentage of the adult population in February, for the years 1994 to 2005. His analysis suggests that these percentages may have been quite small.

Estimating the Numbers Entrained

Details of the way that delta smelt are entrained at the state and federal pumping facilities are described by Miller (2005c), and will not be repeated here. Basically, the total salvage of delta smelt is estimated by sampling the delta smelt entering the facilities and dividing the number of smelt sampled by the sampling fraction. This does not give an estimate of the number of delta smelt entrained because some do not survive from the time that they get entrained into the area around the facility until the time that they reach the pumps, and some that do survive are not diverted into the salvage tanks.

Based on these considerations, the number entrained at Banks Pumping Plant, the state facility, can be estimated using the equation

Observed Salvage = (Number Entrained)x(Louvre Efficiency)x(Prescreen Survival),

where the Louver Efficiency is the probability that a delta smelt approaching the facility will be diverted into salvage tanks by louvers set up for that purpose, and the Prescreen Survival is the survival probability in the Clifton Court Forebay of the facility. Based on this equation, the number entrained is

Number Entrained = (Observed Salvage)/{Louvre Efficiency)x(Prescreen Survival)}.

A similar equation also applies at Tracy Pumping Plant, the federal facility.

In order to estimate the numbers entrained, values are required for the Louvre Efficiency and the Prescreen Survival. Based on the work of others, Miller (2005c) assumes that the Louver Efficiency at Banks is about 0.75 while at Tracy it is about 0.15. It is recognized that the accuracy of these values is rather uncertain.

The estimation of the Prescreen Survival probability used by Miller (2005c) is based on the delta smelt abundance estimates from the Spring Kodiak Trawl, as provided here in Table C3. He excluded the estimated abundance in the Sacramento Ship Channel and related the reducing numbers from one month to the next to the average number of days between samples, to estimate a daily survival rate. The data are shown in Table 5.6.

Based on the comparison of numbers from one month to the next, Miller (2005a,c) estimated that the average daily survival rate is approximately exp(-0.025) = 0.975 per day. I checked this by fitting log-linear models to the data in Table 5.6. The first model that I considered assumed a constant daily survival rate. In that case the expected number of adults in the jth sample in year i is given by

$$Adults_{ij} = \exp(Year_i - \alpha Days_{ij}),$$

where $Year_i$ is a parameter that takes into account the different abundances in the first samples in each year, and $Days_{ij}$ is the number of days between the first and jth samples in the ith year. The parameter α defines the daily survival rate, which is exp(-α). The model was estimated using GenStat (Lawes Agricultural Trust, 2005) with an allowance for over-dispersion in the counts. The estimate of α obtained was -0.0171, giving an estimated daily survival rate of exp(-0.0171) = 0.983, which is slightly higher than the value used by Miller (2005c).

Table 5.6 Data for estimating a daily survival rate for delta smelt. Date is the median sampling date in the month. Adults is the estimated abundance for the month from the Spring Kodiak Trawl, excluding the Sacramento Ship Channel estimate. Year is the year number. Days is the number of days from the median sampling date to the median sampling date for the first sample in the year, i.e. the survival time in days. Fit1 and Fit2 are estimated numbers of delta smelt based on two models described in the main text.

Date	Adults	Year	Days	Fit1	Fit2
08-Jan-02	682202	1	0	997507	755485
06-Feb-02	804189	1	29	607417	655006
06-Mar-02	494792	1	57	376259	570692
20-Feb-03	373413	2	0	430639	444369
18-Mar-03	378966	2	26	276039	275734
16-Apr-03	162113	2	55	168090	161929
14-May-03	64397	2	83	104122	96856.6
14-Jan-04	810718	3	0	901165	921852
13-Feb-04	625316	3	30	539445	540075
10-Mar-04	422210	3	56	345783	339788
06-Apr-04	239023	3	83	217887	210001
05-May-04	39692	3	112	132679	125243
26-Jan-05	514599	4	0	349510	508880
24-Feb-05	176118	4	29	212829	178725
24-Mar-05	52593	4	57	131835	65077
20-Apr-05	33937	4	84	83073	24566

A model allowing for the daily survival rate to vary with the year was also considered. With this model the expected number of adults in the jth sample in year i is given by

$$Adults_{ij} = \exp(Year_i - \alpha_i Days_{ij}),$$

where $\exp(\alpha_i)$ is the daily survival rate in year i. This model did not give a significantly better fit to the data than the first model at the 5% level ($F = 3.56$ with 3 and 8 df, $p = 0.067$), although it was close to doing so. According to this model the estimated daily survival rates for the years 2002 to 2005 are exp(-0.0049) = 0.9951, exp(-0.0184) = 0.9818, exp(-0.0178) = 0.9823, and exp(-0.0361) = 0.9646, respectively. Figure 5.8 shows the observed and expected delta smelt frequencies for the two models considered. The second model is a better fit to the data, particularly for 2005. However, as noted above, it is not quite a significant better fit.

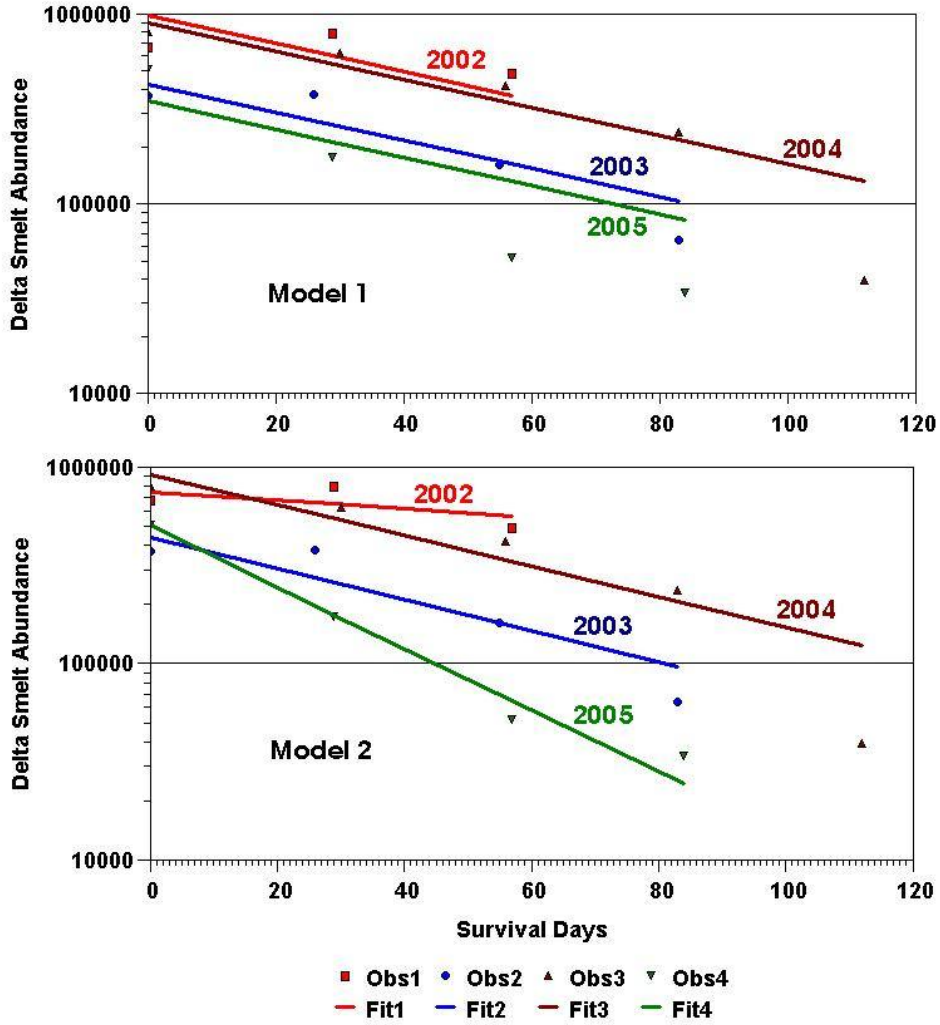

Figure 5.8 Observed and expected delta smelt abundances based on the Spring Kodiak Trawl. The observed abundances for 2002 to 2005 are Obs1 to Obs4, with corresponding expected abundances of Fit1 to Fit4.

The difference between the estimated daily survival rates for 2002 (0.9951) and 2005 (0.9646) from the second model may seem small because both are close to one. However, this difference, if real, would have an enormous impact on the fate of the population because of the difference that is implied for long durations of time. For example the 50 day estimated survival rates are $0.9951^{50} = 0.782$ and $0.9646^{50} = 0.164$. In one case most of the population will survive 50 days while in the other case very few will.

The daily survival rate of exp(-0.025) = 0.9753 used by Miller (2005c) will be assumed for the calculations that follow. This is slightly less than the estimate obtained from the first log-linear model, and within the range of estimates for the years 2002 to 2005 from the second log-linear model, and is a reasonable overall value to use.

The first step in the estimation of the number of entrained adults each year is the calculation of the number of adults entrained each month. These calculations are shown in Table C7. On the left-hand side of the table are the estimated adult delta smelt salvage numbers (the observed salvage divided by the sampling fraction) for November 1993 to May 2005 for the Banks and Tracy pumping stations. These numbers were obtained from the file Smelt_Salvage_Length.xls dated December 1 2006, provided by B.J. Miller, with the corrections noted in Appendix B. The next two columns in Table C7 show the salvage numbers divided by the assumed louver efficiencies (0.75 for Banks and 0.15 for Tracy). These numbers estimate the number of adult actually entering the pump inlet areas.

The time that delta smelt are in the area affected by the pumps is assumed to be equal to the time needed to pump the volume in this area. At Banks the volume is 30,000 acre feet, so the residence time is calculated as the time needed to pump this volume of water at the export rate applying at the time. For example, in November 1993 the average export rate at Banks was 2595 cubic feet a second (cfs). One acre foot is 43,560 cubic feet, and 2595 cfs is equivalent to 60x60x24x2595 = 224,208,000 cubic feet a day. Therefore the time needed to pump 30,000 acre feet is

$$(30{,}000 \times 43{,}560)/(224{,}208{,}000) = 5.83 \text{ days.}$$

Export rates and residence times are shown in columns with these headings in Table C7. The residence times at Banks vary from several to hundreds of days. At Tracy the volume affected by the pumps is assumed to be only 20 acre feet so the residence times are a small fraction of a day.

The prescreen survival rates are given by the daily survival rate applied for the estimated residence times. For example, the prescreen survival rate at Banks in November 1993 is estimated to be $0.9753^{5.83} = 0.864$. The estimated prescreen survival rates are shown under this heading in Table C7. The final two columns of the table give the estimated total numbers of adults entrained at Banks and Tracy. These columns are obtained by dividing the salvage numbers corrected for louver efficiency by the estimated prescreen survival rates.

The estimates shown in Table C7 are based on the assumption that the mortality rate of delta smelt during the residence time in the area of the pumps is the same as everywhere else in the Delta. In fact, if this is the case then no correction for prescreen mortality should be made. This is because there is no extra mortality caused by the pumps. For this reason the calculations shown in Table C7 really show the estimated entrainment assuming that as far as survival is concerned one day resident in the area of the pumps is equivalent to two days residence elsewhere in the delta.

Given the monthly estimated numbers of adults entrained, these can be summed to give the yearly numbers. For this purpose a delta smelt generation is considered rather

than a calendar year. For example, November 1993 to May 1994 represents the entrainment in one year and will be called the 1994 entrainment.

Miller (2005c) provides estimates of adult entrainment numbers calculated as described above, but with various modifications to the parameters. The Banks louver efficiency was varied from 0.25 to 0.75, the Tracy louver efficiency is varied from 0.10 to 0.15, and the daily survival rate is varied from exp(-0.025) to exp(-4x0.025). Table 5.7 shows the estimated numbers entrained for the various scenarios considered.

Table 5.7 Estimated numbers of adult delta smelt entrained in different water years at the Banks and Tracy pumping facilities for various values of the model parameters.

Banks Louver Efficiency	0.75	0.50	0.25	0.75	0.75[b]	0.75	0.75
Tracy Louver Efficiency	0.15	0.15	0.15	0.10	0.15	0.15	0.15
Survival Factor[a]	1.00	1.00	1.00	1.00	2.00	3.00	4.00
Year				Entrained			
1994	1812	1958	2396	2572	1855	1907	1968
1995	4533	6160	11040	5173	4731	4945	5185
1996	16380	19110	27300	21840	16846	17357	17918
1997	14993	15210	15860	22273	15081	15186	15313
1998	5353	5603	6353	7780	5393	5437	5484
1999	14263	14550	15410	21108	14396	14573	14814
2000	40544	45656	60992	55704	41152	41798	42486
2001	30023	31474	35828	43583	30258	30511	30785
2002	19009	22354	32388	25169	19427	19872	20344
2003	40329	47254	68028	53569	41333	42412	43570
2004	24949	28621	39635	33753	25371	25817	26289
2005	5931	6856	9632	7971	6034	6143	6259

[a]The survival factor gives the daily survival in the area of the pumps compared to an assumed value of exp(-0.025) = 0.975 elsewhere in the Delta. For example, a survival factor of 1.0 means that there is no excess mortality in the area of the pumps so the excess prescreen mortality is set at zero. A survival factor of F means that the survival rate in the area of the pumps is exp(-Fx0.025), so that one day near the pumps is equivalent to F days elsewhere in the delta as far as survival is concerned.
[b]This scenario is what is shown in Table C7.

The entrainment figures shown in Table 5.7 do not agree with those provided in Table 1 of Miller (2005c), although they are quite similar. The reason for the discrepancy is not clear, and is not due to the fact that a survival factor of F in Table 5.7 is equivalent to an increase in the exponential mortality rate of F-1 in Table 1 of Miller (2005c). However, the values in Table 5.6 do agree well with those in the file named adult_entrainment.xls, dated January 12, 2006, and provided by B.J. Miller. Some differences (particularly for water year 2003) are due to the values in Table 5.7 being based on corrected adult salvage numbers in the file Smelt_Salvage_Length.xls as described in Appendix B, plus the inclusion here of data from salvage in June 1998 (the only year when June adult salvage occurred).

The results in Table 1 of Miller (2005c) and Table 5.7 are in agreement about the general magnitude of adult salvage and the fact that the numbers are not very sensitive

to the assumptions made about louver efficiencies and the excess mortality in the area of the pumping plants.

Estimating the February Population Size and the Percentage Entrained

Miller (2005c) expressed the estimated adult entrainment numbers for 1994 to 2005 as a fraction of the estimated adult delta smelt population size in February based on Spring Kodiak Trawls. The February population size estimates for 2002 to 2005 are shown in Table C3, but are not available for 1994 to 2001. To overcome this problem, Miller used the 2002 to 2005 data to fit a Beverton-Holt type of relationship between the February Kodiak Trawl estimated abundances (FKT) and the previous FMWT abundance estimate.

The fitted relationship is shown in Figure 2 of Miller (2005c), and has the equation

$$FKT = (FMWT)/(0.000118 + 0.00000105xFMWT),$$

where the parameters were determined by trial and error. This curve does fit the data well, but this is perhaps because there are two parameters to estimate from only four data points. According to this equation, for small values of the FMWT the FKT value is approximately FMWT/0.000118 = 8474.6xFMWT, while for large values of the FMWT the FKT value approaches 1.0/0.00000105 = 952381.0.

There is, however, a problem with the data used to fit the above equation. This is that it uses the total estimated delta smelt abundance for all of the sampling areas shown in Table C3, although the Sacramento Ship Channel was not sampled in 2002 and 2004. This might not matter, except that the estimated abundances in the Sacramento Ship Channel were high in February 2002 and February 2004, comprising about 36% of the total abundance.

To overcome this problem I estimated the function relating FKT to FMWT based on the total adult delta smelt abundance in the areas other than the Sacramento Ship Channel. These abundances for February in the years 2002 to 2004 are 804189, 373413, 625316 and 176118, in order. The corresponding previous FMWT index values are 603, 139, 210 and 74. These, therefore are the data for fitting the function. The least-squares fit is

$$FKT = FMWT/(0.000132 + 0.00000117xFMWT).$$

Figure 5.9 shows the observed and fitted values of FKT, with the curve extrapolated for FMWT values as large as 1100. The fit is not as good as the fit shown in Figure 2 of Miller (2005c), and the assumed Beverton-Holt type of relationship seems questionable. However, more data are required before the appropriate form of the relationship can be determined. The extrapolation to large values of the previous FMWT index is needed if the fitted relationship is used to estimate FKT values before 2002. This is because the largest previous FMWT value before 2002 is 1078 for 1994.

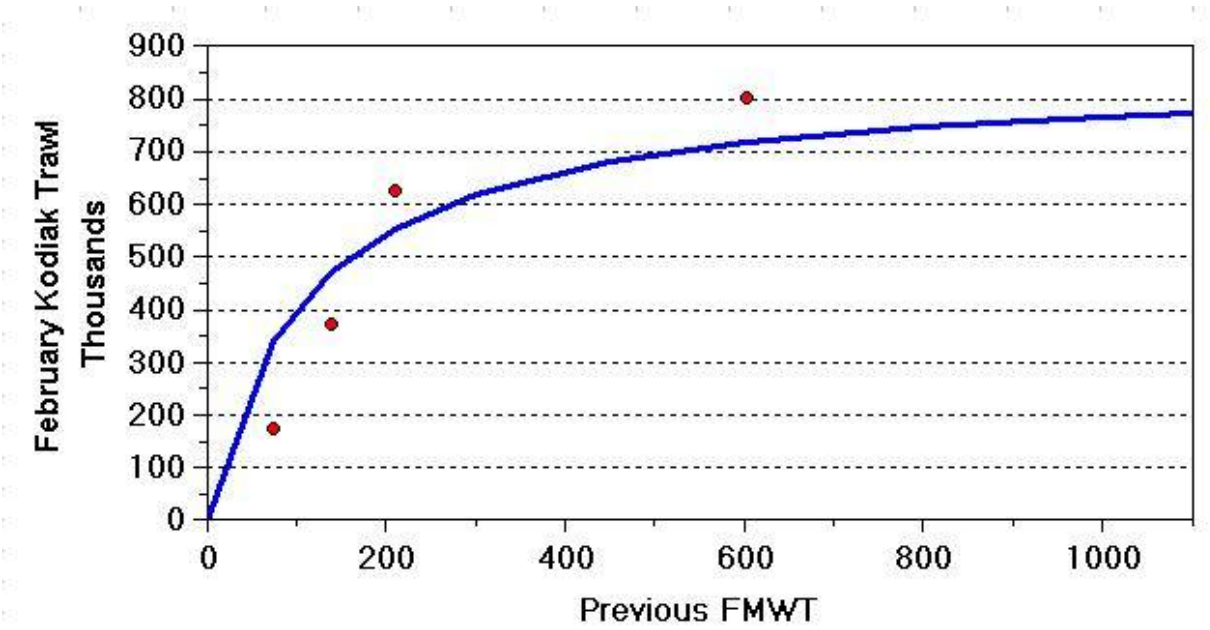

Figure 5.9 Fitted relationship between the February Kodiak Trawl abundance not including the Sacramento Ship Channel, and the previous Fall Midwater Trawl index (—), with the observed Kodiak Trawl values shown (●).

Table 5.8 shows the observed and estimated FKT values for the years 1994 to 2005, and the estimated percentage of adult delta smelt entrained based on these FKT values, for the scenarios shown in Table 5.6, i.e., the entrained numbers shown in Table 5.6 expressed as a percentage of the estimated FKT abundances. The percentages shown in Table 5.8 are higher than those given in Table 3 of Miller (2005c) because the abundance indices used to construct Table 5.8 do not include the Sacramento Ship Channel. As the Ship Channel appears to contain about 36% of the population of adult delta smelt, an approximate correction for not including the abundances for this area involves dividing the percentages in Table 5.8 by 1.36, i.e. multiplied by 0.74. If this correction is made then the values in Table 5.8 are very similar to those given in Table 3 of Miller (2005c).

Alternative Method of Estimating Entrainment

Miller (2005c) also investigated the estimation of entrainment rates based on the density of adult delta smelt close to the pumps, in the Southeast Delta area (Table C3). For this purpose he took the estimated density of adult delta smelt per acre foot in a month, and multiplied this by the total number of acre feet exported in the same month. This then provided an estimate of the total number of adults entrained in the month, assuming that the density of delta smelt near the pumps is similar to the estimated density for the whole of the Southeast Delta.

Table 5.8 Estimated adult delta smelt entrained expressed as a percentage of the abundance estimated from the February Kodiak Trawl excluding the abundance in the Sacramento Ship Channel (FKT). The FKT values for 1994 to 2001 are estimated from the relationship shown in Figure 5.9.

Banks Louver Efficiency			0.75	0.50	0.25	0.75	0.75[b]	0.75	0.75
Tracy Louver Efficiency			0.15	0.15	0.15	0.10	0.15	0.15	0.15
	Survival Factor[a]		1.00	1.00	1.00	1.00	2.00	3.00	4.00
Year	FMWT	FKT	Entrained						
1994	1078	773725	0.2	0.3	0.3	0.3	0.2	0.2	0.3
1995	102	405825	1.1	1.5	2.7	1.3	1.2	1.2	1.3
1996	899	759400	2.2	2.5	3.6	2.9	2.2	2.3	2.4
1997	127	452618	3.3	3.4	3.5	4.9	3.3	3.4	3.4
1998	303	622803	0.9	0.9	1.0	1.2	0.9	0.9	0.9
1999	420	673725	2.1	2.2	2.3	3.1	2.1	2.2	2.2
2000	864	755985	5.4	6.0	8.1	7.4	5.4	5.5	5.6
2001	756	743714	4.0	4.2	4.8	5.9	4.1	4.1	4.1
2002	603	804189	2.4	2.8	4.0	3.1	2.4	2.5	2.5
2003	139	373413	10.8	12.7	18.2	14.3	11.1	11.4	11.7
2004	210	625316	4.0	4.6	6.3	5.4	4.1	4.1	4.2
2005	74	176118	3.4	3.9	5.5	4.5	3.4	3.5	3.6

[a]The survival factor gives the daily survival in the area of the pumps compared to an assumed value of exp(-0.025) = 0.975 elsewhere in the Delta. For example, a survival factor of 1.0 means that there is no excess mortality in the area of the pumps so the excess prescreen mortality is set at zero. A survival factor of F means that the survival rate in the area of the pumps is exp(-Fx0.025), so that one day near the pumps is equivalent to F days elsewhere in the delta as far as survival is concerned.

[b]This scenario is what is shown in Table C7.

There is an obvious problem with this method. There are 16 months of data available with the density of delta smelt estimated. Of these, only three months give a non-zero density in the Southeast Delta. For these three months salvage was observed at both the Banks and Tracy pumping plants. However, for eight of the other months salvage was observed at one or both of the pumping plants but the estimated density of adult smelt in the Southeast Delta was zero. Presumably what is happening here is that the distribution of adult delta smelt is very patchy. Therefore, in any month the density of delta smelt near the pumping plants may be quite different from the density in the samples taken throughout the Southeast Delta. In other words, the estimated density of delta smelt in the whole of the Southeast Delta can be expected to be a poor predictor of the density close to the pumps. I do not consider this method further.

Conclusions

The estimation of the number of adult delta smelt entrained at the Banks and Tracy pumping facilities is in principle quite simple. The observed salvage numbers need to be (i) divided by the sampling fraction to estimate the salvage that would be collected with sampling all of the time, then (ii) divided by the louver efficiency to allow for the fact that some delta smelt miss being diverted to the salvage tanks, and finally (iii) divided by a

factor that takes into account any excess mortality of the delta smelt over and above the mortality expected in the Delta in general while the smelt are in the area affected by pumping.

The first part of this calculation should be straightforward as the sampling fraction should be known accurately. I am not sure about the accuracy of the values used for louver efficiency in part (ii) of the calculation, but the range of values used for the Banks louver efficiency in particular (0.25 to 0.75) presumably covers most possibilities.

The estimation of the general level of mortality in the Delta relies in the assumption that the generally reducing Kodiak Trawl abundances from one month to the next reflect this mortality. This seems reasonable providing that there is no reason to believe that the reductions are due to delta smelt leaving the areas sampled, or, at any rate, that immigration and emigration are more or less balanced. It is interesting that a model for survival that allows the survival rate to vary from year to year nearly gives a significant year effect, although there is not much data. It would surely be worth while to examine the data more carefully in this respect and, in particular, relate the yearly differences in survival to other variables such as the environmental conditions and the availability of prey. It seems that this could be done considering data from different areas in the Delta, although the numbers in specific areas seem quite volatile, often increasing from one month to the next (Table C3).

I believe that the estimated numbers of delta smelt entrained as shown in Table 5.7 are reasonable, given the assumptions. If there are any aspects of salvage that make these assumptions unreasonable then I am not aware of them.

To calculate the percentages of adult delta smelt entrained just requires dividing the numbers entrained by an estimate of the population size of delta smelt. I used the February Kodiak Trawl estimated abundances for this purpose for 2002 to 2005, excluding the abundances in the Sacramento Ship Channel for the years when this area was sampled. As noted in the conclusions for analysis 2(a) above, the Kodiak Trawl was not designed to provide a population estimate of delta smelt, there is some vagueness about the sampling design, and questions about the assumptions that have to be made to produce abundance estimates. Therefore, the Kodiak Trawl abundances should be regarded as approximations to the true abundances. However, in the absence of any other estimates they seem to be the best that is available. On this basis the percentages entrained shown in Table 5.8 can be regarded as the best guess at the true percentages, except that they should possibly be reduced by about 25% because the Kodiak Trawl abundance estimates do not include the Sacramento Ship Channel.

For the years 1994 to 2001 the Kodiak Trawl abundances had to be estimated using the relationship shown in Figure 5.9. For these years this adds an extra element of uncertainty to the percentages entrained shown in Table 5.8, although they can still be thought of as best guesses for the true percentages.

(e) Adult Salvage Measures Related to the Subsequent FMWT Index

The relationship between various measures of adult salvage and the subsequent FMWT index was discussed by Miller (2005d) in relationship to the management of adult entrainment at the Banks and Tracy pumping plants. Miller found no significant relationships, which suggests that the amount of salvage has little effect on subsequent delta smelt numbers.

Regression Analyses

Miller (2005d, Figure 3) shows the FMWT index plotted against the estimated percentage of adult entrainment, the adult salvage divided by the estimated adult population size from the Spring Kodiak Trawl data in the same year, and the adult salvage divided by the previous FMWT index. Some of these data are in the file Adult_Salvage_vs_FMWT dated January 12, 2006, and provided by B.J. Miller. However, this file also has data on the adult salvage divided by the export rates (cfs) for November to March and November to April. These variables will therefore also be considered here.

Table 5.9 shows the data that are used here. These differs from the data used by B.J. Miller (2005d) for several reasons:

(a) Considering adult salvage, the value for 2005 includes the corrections described in Appendix B for the file Smelt_Salvage_Length.xls. Also, in 1998 there was salvage in June, which is included in the value in Table 5.9, but was not included by B.J. Miller. Finally, the 1993 salvage value is not included here because this should be the total salvage from November 1992 to May 1993 but there are no records for November and December 1992 in Smelt_Salvage_Length.xls.

(b) The estimates of adult entrainment shown in Table 5.9 are those that come from the calculations shown in Table C7. They are also the ones shown in the column with footnote b in Table 5.8. It is assumed that the louver efficiencies at the Banks and Tracy pumping stations are 0.75 and 0.15, respectively, and that the mortality in one day near a pumping station is equivalent to two days elsewhere.

(c) The estimated abundance from the February Kodiak Trawl (FKT) are those given in Table C3, excluding the estimated abundances in the Sacramento Ship Channel because this was not sampled in two of the four years. The abundances in Tables 5.8 and 5.9 are the same.

Table 5.9 Data for regressions relating the FMWT index to salvage variables. The variables used to account for the variation in the FMWT index are the Percent Entrained, the adult salvage divided by the February Kodiak Trawl abundance estimate (A/F), the Adult Salvage divided by the previous FMWT index (A/B), the Adult Salvage divided by the export rate (cfs) from November to March (A/C), and the salvage rate divided by the expoer rate from November to April (A/D).

		A	B	C	D	E	F				
Water Year	FMWT	Adult Salvage	Previous FMWT	Exports Nov-Mar	Exports Nov-Apr	Percent Entrained	FKT	A/F	A/B	A/C	A/D
1994	102	447	1078	6602	5818	0.24	773725	0.001	0.41	0.068	0.077
1995	899	2632	102	7371	6721	1.17	405825	0.006	25.80	0.357	0.392
1996	127	5733	899	5972	5676	2.22	759400	0.008	6.38	0.960	1.010
1997	303	2509	127	5891	5663	3.33	452618	0.006	19.76	0.426	0.443
1998	420	1111	303	6486	5649	0.87	622803	0.002	3.67	0.171	0.197
1999	864	2484	420	4630	4660	2.14	673725	0.004	5.91	0.536	0.533
2000	756	12216	864	9159	8508	5.44	755985	0.016	14.14	1.334	1.436
2001	603	6245	756	8152	7444	4.07	743714	0.008	8.26	0.766	0.839
2002	139	6865	603	8814	8054	2.42	804189	0.009	11.38	0.779	0.852
2003	210	14359	139	9114	8341	11.07	373413	0.038	103.30	1.575	1.721
2004	74	8148	210	9834	8878	4.06	625316	0.013	38.80	0.829	0.918
2005	26	2000	74	8804	8315	3.43	176118	0.011	27.03	0.227	0.241

Figure 5.10 shows the relationship between the FMWT index and the other variables being considered. This figure also shows estimated regression lines. None of the estimated regression relationships are at all significant.

The first regression equation considered relates the FMWT index to the estimated percentage of adult delta smelt entrained. The estimated equation is

$$FMWT = 416.6 - 11.77(\%\ Entrained).$$

This equation does predict that as the percent entrained increases then the FMWT index decreases. However the equation only accounts for 1.1% of the variance in the FMWT index, which is not at all significant ($t = -0.33$, $p = 0.748$).

The second equation considered relates the FMWT index to the adult salvage divided by the February Kodiak Trawl abundance estimate. The estimated equation is

$$FMWT = 428.2 - 5061.3(Salvage/FKT).$$

Here Salvage/FKT is an index of the fraction of the population entrained. The coefficient of this index is negative, suggesting that as the fraction entrained increases the FMWT decreases. However the equation only accounts for 2.5% of the variance in the FMWT index and is not at all significant ($t = -0.50$, $p = 0.627$).

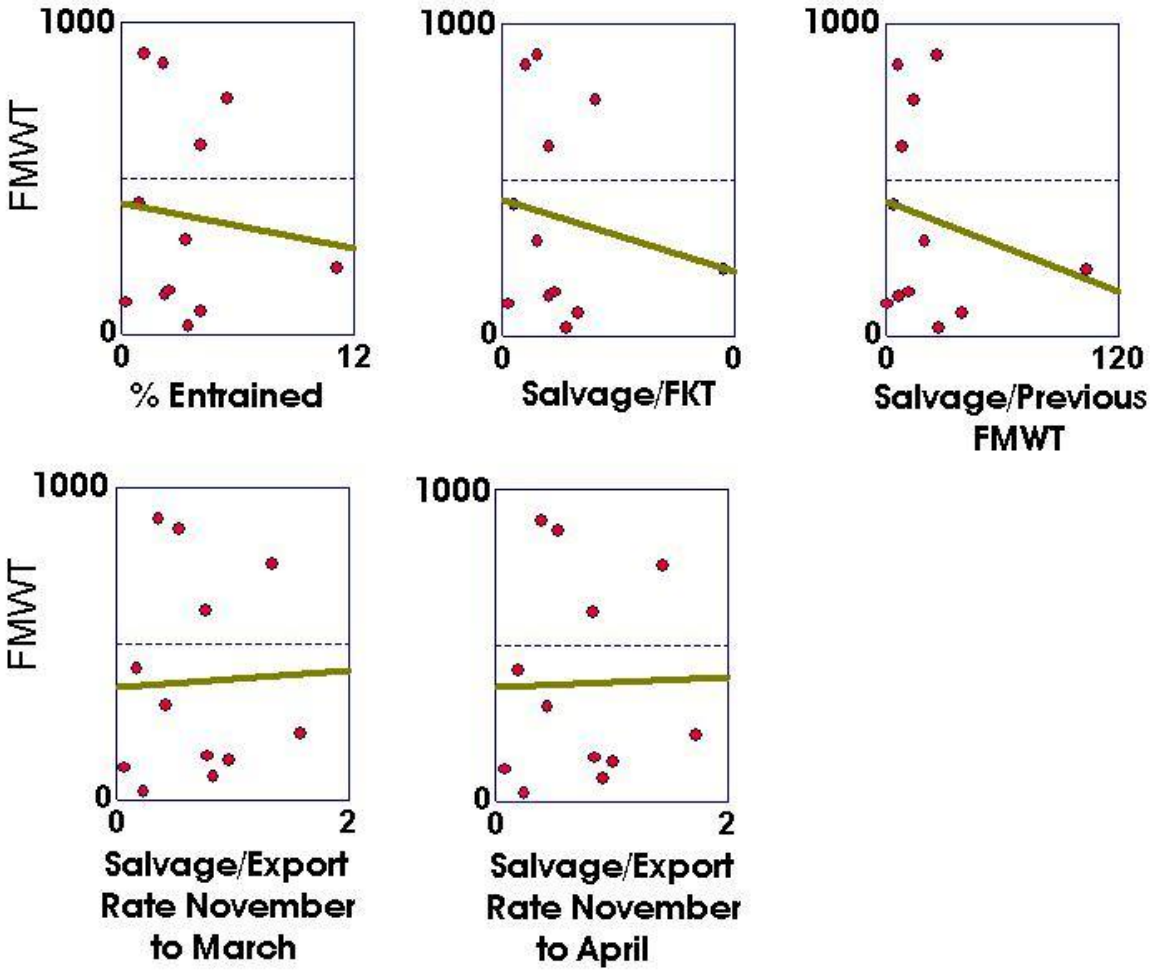

Figure 5.10 The FMWT index plotted against various variables related to the salvage at the Banks and Tracy pumping plants.

The third regression equation considered related the FMWT index to the adult salvage divided by the value of the previous FMWT index. The estimated equation is

$$FMWT = 429.8 - 2.396(Salvage/FMWT_{-1}).$$

Here $Salvage/FMWT_{-1}$ is another index of the fraction of the adult delta smelt population entrained. Again the coefficient of the index is negative, suggesting that as the fraction of adults entrained increases the FMWT index decreases. The equation only accounts for 4.3% of the variance in the FMWT index and is not at all significant ($t = -0.67$, $p = 0.518$). The plots in Figure 5.10 show that this regression equation as well as the two previous ones are effected very much by the data point for 2003. The estimated percentage of adult delta smelt entrained is 11.1% for that year, leading to high values of Salvage/FKT and $Salvage/FMWT_{-1}$, while the FMWT index was fairly low at 210.

The fourth regression equation considered relates the FMWT index to the salvage divided by the export rate (cfs) from November to March. The estimated equation is

$$FMWT = 358.6 + 27.33(Salvage/Exports_{Nov\text{-}Mar}).$$

In this case the export variable is proportional to the amount of water pumped, so that $Salvage/Exports_{Nov\text{-}Mar}$ is an index of the salvage rate per unit volume of water. the coefficient of this index is positive, suggesting that the FMWT index increases as the salvage rate per unit volume of water increases, which does not seem sensible. However, the equation accounts for only 0.2% of the variance in the FMWT index, which is very far from being significant ($t = 0.12$, $p = 0.904$).

Finally, the last regression equation considered is similar to the previous one, but uses the export rate for November to April instead of from November to March. The estimated equation is

$$FMWT = 364.7 + 16.97(Salvage/Exports_{Nov\text{-}Apr}).$$

This equation accounts for a mere 0.07% of the variance in the FMWT index, which is again very far from being significant ($t = 0.08$, $p = 0.935$). The plots in Figure 5.10 confirm the complete lack of a relationship between the FMWT index and the Salvage/Exports indices.

In an e-mail B.J. Miller suggested some further regression equations that should be considered, relating the FMWT index to the salvage directly, to the salvage and the previous FMWT index value, and relating the percentage change in the FMWT from one year to the next to salvage divided by the previous FMWT index. The first of these regressions gives the estimated equation

$$FMWT = 383.6 - 0.0012(Salvage)$$

which accounts for only 0.03% of the variance in FMWT and has a very insignificant coefficient ($t = -0.05$, $p = 0.958$). Adding the previous FMWT index into the equation changes it to

$$FMWT = 388.7 - 0.0012(Salvage) - 0.0115(FMWT_{-1}),$$

which still accounts for only 0.05% of the variance in the data, with the coefficients of Salvage and $FMWT_{-1}$ being very insignificant ($t = -0.05$ with $p = 0.962$ and $t = -0.04$ with $p = 0.970$, respectively).

The percentage change in the FMWT index from one year to the next is calculated as $FMWT\% = 100(FMWT - FMWT_{-1})/FMWT_{-1}$. This is a measure of the change in delta smelt abundance, which might be related to $Salvage/FMWT_{-1}$, a measure of the proportion of the

adult delta smelt population entrained. The division by $FMWT_{-1}$ for both FMWT% and Salvage/$FMWT_{-1}$ could introduce some correlation. However the estimated regression equation

$$FMWT\% = 60.2 + 0.484(Salvage/FMWT_{-1})$$

accounts for only 0.3% of the variation in FMWT% and the regression coefficient is not at all significant ($t = 0.17$, $p = 0.871$).

Conclusions

There is no evidence of any correlation between the FMWT index and the salvage related variables considered here.

6. A Table Summarizing All of the Analyses

The following table provides a summary of all of the analyses considered in this report.

Table 6.1 Analyses discussed above as they relate to export effects, particularly effects on the abundance of delta smelt.

Analysis	Comments
2. Changes in salvage rates for 2000-04 compared to 1994-99.	Changes in the mean estimated winter salvage values between 1994-99 and 2000-05 are extremely unlikely to have occurred by chance. Similarly, changes in the winter salvage densities (the salvage values per volume of water exported) and changes in the winter salvage densities divided by the previous FMWT (Fall Midwater Trawl) abundance indices are quite unlikely to have occurred by chance. It seems that there has been a general increase in the salvage of the fish considered since 1999, and this increase is not accounted for by changes in the amount of water pumped, or changes in the amount of water pumped combined with changes in the abundance of fish.
2a. Winter salvage related to the Export/Inflow ratio.	The idea that increased winter salvage is related in a simple linear way to increases in the Export/Inflow (E/I) ratio in recent years is not supported by the 1993-2004 data on a monthly or daily basis. Very high E/I ratios are actually associated with very low salvage rates. On a daily basis the highest salvage levels have been observed with E/I ratios of about 20%. At these levels of E/I there is also a great deal of variation in the salvage rates, which it would be interesting to relate to other factors. The factors involved might not be the same as those responsible for the low salvage at low and high E/I ratios. The low salvage rates at low E/I ratios is presumably due to a relatively small amount of water passing through the pumps. The reason for the low salvage rates at high E/I ratios is not clear.
3. The STN delta smelt abundance index related to salinity at Jersey Point and the previous FMWT abundance index.	Based on 1988-2005 data, a regression equation that relates the STN (Summer Townet) delta smelt abundance index to the water salinity at Jersey Point in the fall (October-December) and to the FMWT abundance index prior to the STN index accounts for 72% of the variation in the data. The fit is not significantly improved by adding winter (November to March) export rates as an explanatory variable. There is some indication that the residuals from the model may be related to winter export rates, and also that the salinity at Jersey Point may be positively related to winter export rates, but these apparent effects are not significant.

4(a). The relationship between adult and juvenile delta smelt abundance.	A regression of log(STN) values against Log(FMWT) gives clear evidence of a positive relationship between the two indices in the same water year. There are, however, apparent patterns in the regression residuals which suggest that these may be correlated, the patterns are related to the values of a missing covariate, or the equation changed over the period being considered. The residuals have been negative since 2000, and the residual for 2005 is the most extreme ever observed. When a regression with correlated errors is considered it accounts for slightly more of the variation in the data than the ordinary regression, at the expense of estimating one more parameter. It does not eliminate the pattern in residuals. A regression of Log(FMWT) values against the previous Log(STN) values also gives clear evidence of a positive relationship, but with some apparent patterns in the residuals. A slightly better fit to the observed data can be obtained using a regression with correlated errors, but this still does not account for the low Log(FMWT) values in 2004 and 2005, and the estimated correlation structure involving Log(FMWT) being related to the regression residual two years before is hard to account for.
4(b). The effect of winter exports on the delta smelt STN juvenile abundance index.	The apparent relationship between Log(STN) values and the prior winter exports over the period 1969 to 2005 seems questionable. There are patterns in the regression residuals that indicate correlation in these residuals, a missing covariate, or change with time in the mean of the Log(STN) values. If correlated residuals are allowed for then the estimated effect of winter exports is small and not significant. If the mean of Log(STN) is assumed to change between 1982 and 1983 then the estimated change is highly significant and this model accounts for far more variation than any of the other models considered. Given the change in the mean of Log(STN) between 1983 and 1983 there is no evidence that Log(STN) values are related to winter exports. Nevertheless, systematic patterns in the residuals suggest that Log(STN) may be determined to some extent by some unmeasured covariate.
4(c). The effect of winter exports on the delta smelt FMWT sub-adult abundance index.	The regression of Log(FMWT) values against the winter export rate is highly significant, but there are patterns in the residuals. If these patterns are modeled assuming correlated regression residuals then the correlation in regression residuals is found to be significant and the estimated regression accounts for 36.4% of the variation in the data. There is no longer a significant effect of winter exports, but still some patterns in the regression residuals. Alternatively, assuming a change in the mean of Log(FMWT) between 1982 and 1983 accounts for 26.6% of the variation in Log(FMWT) values, and the estimated effect of winter exports is approaching significance assuming that it was constant over the full period 1967 to 2005. There are still patterns in the residuals for the model assuming a change in the mean of Log(FMWT) between 1982 and 1983. If these are modeled assuming correlated regression residuals then 40.5% of the variation in Log(FMWT) values can be accounted for without any estimated winter export effects. This model assumes, however, that Log(FMWT) values are related to regression residuals two years before, which is hard to account for. Therefore a model with a change in the mean between 1982 and 1983 without correlated residuals may be preferred. None of the models can account for the very low FMWT values in 2004 and 2005.

4(d). The effect of spring and summer exports on the STN abundance index for delta smelt.	A regression of Log(STN) values against total exports in acre feet from March to July in the same year is clearly significant but it under-estimates the Log(STN) values up to the early 1980s and then over-estimates the values. There is an apparent shift in the mean of Log(STN) between 1982 and 1983. Allowing for a change in the mean, the effect of total exports is no longer quite significant, although the model including an export effect accounts for 53.0% of the variation in the data. When the observed and expected values of Log(STN) are plotted against years it is apparent that there are still patterns in the residuals, suggesting that there is a variable affecting the results that is not in the model. The model does not account for the very low Log(STN) value in 2005.
5(a). The estimation of delta smelt abundance based on Spring Kodiak Trawl data.	This analysis provides estimates of adult delta smelt abundances in January, February and March based on Kodiak trawl sampling, which has been carried out since 2002. Given various uncertainties associated with the assumptions behind these estimates they can be regarded as initial approximations which may be modified when more information about these assumptions becomes available.
5(b). Summer overlap of delta smelt prey and the FMWT index.	Based on 1985-2004 data, there is a highly significant relationship between the FMWT delta smelt abundance index and B.J. Miller's index of the geographical overlap between delta smelt and zooplankton prey (*E. affinis* + *P. forbesi*, or *P. forbesi* alone).
5(c). Delta smelt adult salvage related to abundance east of Franks Tract.	Based on 2002-2005 data, the total adult salvage at the state and federal pumping facilities on a monthly basis (January to May) is strongly related to the estimated abundance of delta smelt east of Franks Tract as estimated from the Spring Kodiak Trawl.
5(d). Adult delta smelt entrainment at the Banks and Tracy pumping stations.	Subject to a number of assumptions it appears that the number of adult delta smelt entrained at the state and federal pumping stations 1994-2005 represents a small percentage of the total population. In most years it is estimated that about 5% of adults are entrained, but in 2003 the percentage may have been anything up to 18% or more.
5(e). Adult salvage related to the subsequent FMWT index.	Based on 1994-2005 data, no significant relationship is found between the FMWT delta smelt abundance index and various measures of the earlier salvage and exports. All fitted regression equations showed an extremely small percentage of the variation in the FMWT index accounted for.

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I would like to thank the authors of the analyses reviewed in this report for helpful comments and suggestions concerning both their own and other analyses. In addition, I am thankful to Sheila Greene (California Department of Water Resources) for facilitating the collection of data and other materials needed for the reviews, for providing suggestions about what this report should contain, and for pointing out errors in the text. Finally, I thank Lyman McDonald (Western EcoSystems Technology, Inc.) for reading an earlier version of this report and making a number of suggestions for improvements to the text.

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Appendix A: Abbreviations and Definitions

CPUE	The catch per unit effort. This can be either the average catch of a target species per tow, or the catch per m^3 of water sampled.
FKT	February Kodiak Trawl sampling. Sampling of delta smelt has been conducted at 40 stations throughout the Sacramento-San Joaquin Delta in alternate weeks from January to May, since 2002, with some months missing in 2002 and 2003. This has provided about 80 trawls per month. In addition, supplemental sampling has been conducted in some months in areas with the highest densities of delta smelt. Stations in the manmade part of the Sacramento Ship Channel were not included in the regular sampling program, but were often included in the supplemental sampling. An estimated delta smelt adult abundance is available for February in each of the sampled years.
FMWT	Fall Midwater Trawl sampling. Sampling has been conducted throughout the Sacramento-San Joaquin Delta from August to December since 1967, except in 1974 and 1979. There were about 80 stations sampled per month before 1993, and about 100 stations sampled per month sampled from 1993 on, with one trawl per station. This sampling provides data on the abundance of sub-adult delta smelt in individual tows, which can be used to estimate delta smelt densities in different parts of the delta. The FMWT abundance index is calculated from these densities.
STN	Summer Tow Net sampling. Sampling of delta smelt has been conducted since 1985 at 37 stations throughout the Sacramento-San Joaquin Delta, approximately every two weeks in the summer, beginning in June. This has provided about 192 tows per month. The sampling protocol was originally based on the size of striped bass rather than the calendar month, so that the timing of samples has varied from year to year. The STN delta smelt abundance index is for juveniles.

Appendix B: Sources of Data

Name of File	Date	Source	Contents
Salvage_Data_Jan_93_-_Sept_05_-_4.xls	1/9/2006	B. Herbold	Contains data on total exports, winter (November-March) exports, FMWT indices, and total (adult and juvenile) salvage for the two pumping stations, for the years 1993 to 2005, for delta smelt and the other fish considered by Herbold *et al*. (2006).
JP_EC_IEP_HECDSS_Avg_FallAvg_to_Greene_Manly.xls	1/9/2006	M. Guerin	Contains monthly average salinity values (EC) at Jersey Point in the Delta, from September 1964 to March 2005.
Regressjpecfmwtvsfolyrstn_1987_to_Greene_Manly.xls	1/9/2006	M. Guerin	Contains the regression relating the STN abundance index to the salinity at Jersey Point and the previous FMWT abundance index.
DS_Export_Analysis_for_Sheila.xls	1/20/2006	T. Swanson	Contains monthly export amounts (taf) and rates (cfs) for 1967-2005, and logarithms of the FMWT and STN indices for the years when they are available.
Monthly_Exports_57-05.xls	1/12/2006	B.J. Miller	Contains monthly export rates (cfs) from January 1956 to October 2005 from the two pumping stations.
Kodiak_Population_Data.xls	1/12/2006	A.S. Britton	Results from 928 Spring Kodiak Trawls with CPUE results for different sampling areas.
Consolidated_Area_Volume.xls	1/20/2006	B.J. Miller	Volumes in different parts of the Sacramento-San Joaquin Delta as calculated by BJ.
1985-2005_CB-Matrix.xls	20/12/2005	A.S. Britton	Results from zooplankton sampling using a Clarke-Bumpus net for the years 1985-2005.
Tns_Effort.xls	18/1/2006	A.S. Britton	Results from summer townet surveys for 1985 to 2004.
Adult_Salvage_and_East_of_Franks.xls	12/1/2006	B.J. Miller	Data for calculations of various regressions relating delta smelt adult salvage to the abundance of delta smelt east of Franks Tract and other variables.

Smelt_Salvage_Length.xls	31/12/2005	B.J. Miller	Salvage data, with separate counts for the two pumping stations with juvenile and adult counts indicated. There are three days when the counts were not classified as juvenile or adult. Based on information from B.J. Miller the counts were classified as adults for February 15 and 16, 2005, and juvenile for May 11, 2005. In addition, the file does not include salvage for 792 adults at the Tracy pumping facility in December, 2002.
Adult_Entrainment.xls	1/12/2006	B.J. Miller	Calculates adult delta smelt numbers entrained at the two pumping stations based on specific assumptions about louver efficiency and daily survival.
Adult_Salvage_vs_FMWT.xls	1/12/2006	B.J. Miller	Contains data for the FMWT index and its relationship with the earlier adult salvage.

Appendix C: Tables

Winter Salvage and the Export to Inflow Ratio

Table C1 Monthly winter salvage and the corresponding export to inflow ratio (E/I), FMWT index, and expected salvage according to a fitted log-linear model for all salvage (Fit1) and adult salvage only (Fit2). The months in bold have the highest total salvage in each water year.

Year	Month	Water Year	E/I	FMWT	Adult Salvage	Juvenile Salvage	Total Salvage
1993	11	1994	47	1078	0	0	0
1993	12	1994	48	1078	88	0	88
1994	1	1994	35	1078	16	0	16
1994	**2**	**1994**	**27**	**1078**	**174**	**0**	**174**
1994	3	1994	26	1078	169	0	169
1994	11	1995	54	102	0	0	0
1994	12	1995	45	102	54	0	54
1995	**1**	**1995**	**20**	**102**	**2057**	**0**	**2057**
1995	2	1995	12	102	481	0	481
1995	3	1995	4	102	16	0	16
1995	11	1996	35	899	0	0	0
1995	12	1996	18	899	0	0	0
1996	**1**	**1996**	**32**	**899**	**4177**	**12**	**4189**
1996	2	1996	6	899	1290	0	1290
1996	3	1996	5	899	155	0	155
1996	11	1997	53	127	12	0	12
1996	12	1997	14	127	18	0	18
1997	1	1997	1	127	0	0	0
1997	2	1997	2	127	80	0	80
1997	**3**	**1997**	**19**	**127**	**1730**	**0**	**1730**
1997	11	1998	53	303	0	0	0
1997	12	1998	43	303	281	0	281
1998	1	1998	19	303	130	0	130
1998	2	1998	1	303	24	0	24
1998	**3**	**1998**	**2**	**303**	**592**	**0**	**592**
1998	11	1999	21	420	0	0	0
1998	12	1999	4	420	16	0	16

1999	1	1999	12	420	28	0	28
1999	**2**	**1999**	**6**	**420**	**1466**	**0**	**1466**
1999	3	1999	9	420	564	0	564
1999	11	2000	57	864	24	0	24
1999	12	2000	34	864	126	0	126
2000	1	2000	43	864	802	0	802
2000	**2**	**2000**	**15**	**864**	**7819**	**0**	**7819**
2000	3	2000	11	864	2719	27	2746
2000	11	2001	62	756	304	6	310
2000	12	2001	53	756	192	0	192
2001	1	2001	36	756	181	0	181
2001	**2**	**2001**	**36**	**756**	**3870**	**0**	**3870**
2001	3	2001	29	756	1398	2350	3748
2001	11	2002	49	603	0	0	0
2001	12	2002	32	603	1129	0	1129
2002	**1**	**2002**	**29**	**603**	**5231**	**0**	**5231**
2002	2	2002	42	603	280	0	280
2002	3	2002	33	603	225	0	225
2002	11	2003	50	139	0	0	0
2002	12	2003	29	139	2800	0	2800
2003	**1**	**2003**	**17**	**139**	**9549**	**0**	**9549**
2003	2	2003	27	139	1491	0	1491
2003	3	2003	41	139	483	0	483
2003	11	2004	56	210	0	0	0
2003	12	2004	29	210	126	0	126
2004	**1**	**2004**	**31**	**210**	**4594**	**0**	**4594**
2004	2	2004	23	210	1161	0	1161
2004	3	2004	21	210	2267	0	2267
2004	11	2005	60	74	0	0	0
2004	12	2005	48	74	0	0	0
2005	**1**	**2005**	**33**	**74**	**1647**	**0**	**1647**
2005	2	2005	30	74	353	0	353
2005	3	2005	19	74	0	0	0

Relationship Between Delta Smelt Abundance and Exports

Table C2 Data used for Swanson's (2005) analyses of the relationship between the summer townet survey (STN) abundance index, the fall midwater trawl (FMWT) abundance index, and the relationship between these indices and winter and spring-summer water exports.

Calendar Year	STN[1]	FMWT[2]	Winter Exports[3]	Mar-Jul Exports[4]
1967		414	948.2	585.9
1968		696	1969.6	1491.6
1969	2.5	315	4351.4	937.1
1970	32.5	1673	1459.0	1237.2
1971	12.5	1303	2847.5	1553.3
1972	11.1	1265	3555.9	1775.3
1973	21.3	1145	2159.7	1556.9
1974	13.0		4240.7	2257.1
1975	12.2	697	5234.0	1657.2
1976	50.6	360	7984.8	1613.0
1977	25.8	481	4375.9	550.3
1978	62.5	572	7964.2	1683.1
1979	13.3		4302.5	1929.4
1980	15.8	1653	5695.5	1616.8
1981	19.8	374	6714.2	1690.8
1982	10.7	330	7485.3	2041.5
1983	2.9	132	8424.4	1352.9
1984	1.2	182	4045.9	2157.8
1985	0.9	110	7525.5	2279.0
1986	7.9	212	6941.4	1729.1
1987	1.4	280	6346.8	1903.6
1988	1.2	174	9334.2	2209.4
1989	2.2	366	8805.6	2497.6
1990	2.2	364	10374.6	1974.0
1991	2.0	689	5955.2	1447.4
1992	2.6	156	6369.6	1111.3
1993	8.2	1078	7656.0	1676.2
1994	13.0	102	6526.9	839.4
1995	3.2	899	7671.8	1723.7

1996	11.1	127	6132.5	1954.9
1997	4.0	303	4856.6	1893.8
1998	3.3	420	5851.1	1177.5
1999	11.9	864	4693.5	1833.4
2000	8.0	756	9175.9	2105.7
2001	3.5	603	7805.2	1449.8
2002	4.7	139	9237.0	1769.8
2003	1.6	210	9666.5	2355.7
2004	2.9	74	10323.8	2003.9
2005	0.3	26	8684.1	2238.7

[1]The summer townet abundance index is based on sampling delta smelt from June to August.

[2]The fall midwater trawl abundance index is based in sampling delta smelt from September to December.

[3]Winter exports are the average export rate in cubic feet a second from December to March, starting in December of the year before the one shown in column 1.

[4]March to July exports are the total acre-feet.

Delta Smelt Abundance Estimated Using the Spring Kodiak Trawl Data

Table C3 Estimated abundance of delta smelt for samples taken in 14 area of the Sacramento-San Joaquin Delta, January 2002 to May 2005. Blanks in the table indicate that no sampling was conducted in the area in the month indicated.

		Napa River	Carqu-inez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Lower San Joaquin River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta	Sac. Ship Channel	Total
2002	Jan	0	32733	95042	177308	30614	17492	12038	0	134925	152218	3168	4170	23095		682802
	Feb	0	13783	29889	338763	0	58459	1526	3065	161001	197703	0	0	0		804189
	Mar	5131	0	7765	106394	0	159574	22178	141768	8491	23852	13262	6377	0		494792
2003	Feb	0	0	133157	22204	44166	26496	95405	0	14389	26937	6942	0	3716	208215	581628
	Mar	0	0	151124	10115	40695	83850	60514	12107	192	9747	0	10623	0	77923	456889
	Apr	0	0	10465	0	0	50764	7423	7059	3485	82916	0	0	0	169678	331791
	May	0	0	20467	0	13974	6559	16272	0	5691	0	0	1434	0		64397
2004	Jan	5367	0	7729	278630	21168	3282	2152	0	165907	268331	45529	1522	11100		810718
	Feb	0	0	20043	81926	2991	179990	1418	0	56739	265574	16634		0		625316
	Mar	0	0	95354	38169	17791	104053	0	0	9565	138916	10391	7972	0		422210
	Apr	0	0	0	0	7280	108544	3525	3009	21096	95568	0	0	0	73277	312300
	May	0	0	0	0	0	8754	2833	0	15318	12786	0	0	0	187698	227390
2005	Jan	0	0	140021	84055	36069	175852	21404	0	0	52240	2293	2665	0	68148	582747
	Feb	16516	0	16992	72169	6552	37788	23189	0	2912	0	0	0	0	100007	276125
	Mar	0	0	7805	6646	8710	20282	7200	1950	0	0	0	0	0	108169	160762
	Apr	0	0	7492	1167	2955	16608	2632	3082	0	0	0	0	0	95627	129564
	May			0	0	0		3505							187164	190669
	Total	27014	46516	743347	1217547	232963	1058348	279711	172040	599712	1326787	98219	34763	37911	1088741	6963619

Summer Overlap of Delta Smelt and Prey and the FMWT Index

Table C4 Estimated delta smelt numbers based on the Summer Townet surveys (STN) for the years 1985 to 2004. Blanks indicate that no samples were taken.

Year	San Pablo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta	Total
1985	0	0	0	0	0	37	373				7	0	4		0	421
1986	0	0	0	133	31	230	2922				37	0	0		35	3388
1987				0	21	0	3161				60	41	0		0	3281
1989	0	0	0	36	21	0	705				0	0	0		10	772
1990	0	0	0	40	10	56	622				60	9	3		0	799
1991	0	0	0	16	3	19	2805				70	32	0		0	2945
1992	0	0	0	24	0	94	311				30	0	0		0	459
1993	0	0	482	2089	5	413	2373				477	0	0		0	5840
1994	0	0	526	346	41	199	3019				308	0	3		0	4442
1995	28	53	234	942	7	77	14				5	0	0		0	1359
1996	195	40	394	2138	57	1136	1544				328	0	0		0	5832
1997	0	0	307	169	0	439	1212				45	0	0		0	2172
1998	380	165	1051	1063	66	31	35				5	0	0		0	2795
1999	130	10	1665	2681	47	1062	1368				97	27	0		0	7086
2000	0	0	44	1558	176	398	1927				134	0	0		0	4237
2001	0	0	0	483	10	60	2787				164	0	0		0	3505
2002	0	0	0	242	0	80	843				30	0	0		0	1194
2003	0	0	44	24	5	492	446				22	0	0		0	1033
2004	0	0	131	36	0	77	69				20	0	0		0	333

Table C5 Estimated zooplankton densities (numbers per m^3) in different areas in the delta. Blanks indicate that no sampling was done in the year and area concerned.

Density of *Eurytempora affinis*

Year	San Pablo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta
1985				622.8	1339.6	3304.8	491.4				581.5	90.5	0.0		25.7
1986				2039.9	955.4	3258.0	478.9				797.8	38.4	291.3		0.0
1987				27.2	307.5	560.5	414.5				398.0	98.4	254.7		5.5
1989				1.4	939.4	7.6	0.0				5.9	0.0	0.0		0.0
1990				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1991				0.0	13.1	1.3	8.1				0.0	0.0	0.0		0.0
1992				0.4	0.0	1.5	0.0				0.0	0.0	0.0		0.0
1993			0.0	1.3	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1994				0.0	0.0	0.0	0.0					0.0	0.0		0.0
1995				0.0	0.0	0.0	12.6					0.0	0.0		
1996				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1997				0.0	0.0	0.0	0.0				0.0	0.0	0.0		
1998	0.0		0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1999	0.0			0.0	12.7	9.1	0.0				0.0	0.0	0.0		0.0
2000	0.0			0.0	11.7	0.0	0.0				0.0	0.0	0.0		0.0
2001	0.0			0.0	0.0	0.0	0.0					0.0	0.0		0.0
2002	0.0			0.0	0.0	0.0	1.3				0.0	0.0	69.0		0.0
2003	0.0			0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
2004	0.0			0.0	0.0	0.0	0.0				0.0	0.0	13.9		0.0

Table C5 Continued

Density of *Pseudiaptomus forbesi*

Year	San Peblo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta
1985				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1986				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1987				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1989				752.0	10262.9	2596.2	2539.2				4431.0	2674.3	5617.8		1104.2
1990				303.3	3515.8	1630.1	4440.9				5800.2	3707.5	1942.5		2708.0
1991				107.7	3645.0	1047.3	2876.3				3287.6	2869.5	3462.6		1969.5
1992				204.0	521.9	1653.0	3020.7				3973.8	3507.9	925.3		1564.3
1993			42.1	368.5	6803.6	1894.3	1589.6				2642.5	3274.1	693.6		1092.3
1994				20.1	198.3	49.1	989.0					1174.8	2506.3		677.5
1995				2642.6	2481.7	2160.8	2356.8					3686.2	1342.7		
1996				32.5	1692.2	238.2	670.2				1846.4	796.6	704.0		168.4
1997				350.5	1269.9	493.7	641.8				1597.4	986.0	5456.7		
1998	0.0		62.5	884.3	3979.8	360.7	1531.8				3323.9	2027.3	249.1		4934.0
1999	0.0			587.2	4164.3	1845.5	2246.4				2272.9	3012.8	4578.3		1674.3
2000	0.0			63.0	2883.2	688.8	1544.3				1272.5	2776.4	3322.8		3455.7
2001	0.0			15.6	169.7	48.0	841.4					339.2	1371.1		500.1
2002	0.0			16.7	103.1	152.4	765.3				2221.4	817.2	7801.2		2311.8
2003	0.0			19.9	1185.9	172.5	984.3				1546.7	1441.8	5722.1		872.9
2004	1.2			7.8	185.3	50.6	484.0				507.4	2418.1	3751.3		2890.3

Table C5 Continued

Density of *Acartiella sinensis*

Year	San Peblo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta
1985				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1986				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1987				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1989				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1990				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1991				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1992				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1993			0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1994				84.5	110.6	243.4	1375.6					147.9	0.0		52.1
1995				16.2	0.0	0.0	58.3					0.0	0.0		
1996				40.5	48.7	78.9	112.4				0.0	10.3	0.0		0.0
1997				38.4	58.0	32.6	123.4				0.0	0.0	0.0		
1998	0.0		3.2	22.8	0.0	22.6	0.0				0.0	0.0	0.0		0.0
1999	0.0			0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
2000	0.0			0.0	0.0	0.0	6.8				0.0	0.0	0.0		0.0
2001	0.0			18.2	23.5	37.3	243.5					4.5	0.0		0.0
2002	0.0			6.8	34.4	37.1	174.0				292.3	0.0	0.0		0.0
2003	0.0			7.8	125.3	103.5	97.6				91.0	0.0	0.0		0.0
2004	1.2			8.8	80.9	117.2	828.2				32.6	20.2	0.0		7.6

Table C5 Continued

Density of *Tortanus species*

Year	San Peblo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta
1985				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1986				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1987				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1989				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1990				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1991				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1992				0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1993			0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1994				13.2	74.1	0.0	0.0					0.0	0.0		0.0
1995				59.0	0.0	0.0	0.0					0.0	0.0		
1996				43.8	0.0	10.5	0.0				0.0	0.0	0.0		0.0
1997				45.1	0.0	0.0	0.0				0.0	0.0	0.0		
1998	0.0		136.5	95.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0
1999	124.7			15.8	0.0	0.0	0.0				0.0	0.0	0.0		0.0
2000	0.0			77.6	8.7	3.0	0.0				0.0	0.0	0.0		0.0
2001	0.0			100.4	22.5	32.0	0.0					0.0	0.0		0.0
2002	0.0			66.5	38.3	5.4	0.0				0.0	0.0	0.0		0.0
2003	0.0			166.1	94.8	8.6	0.0				0.0	0.0	0.0		0.0
2004	9.8			68.9	71.8	57.9	2.6				1.2	0.0	0.0		0.0

Table C6 Overlap indices for delta smelt and zooplankton in different areas of the delta. Blanks indicate that there was no sampling of delta smelt and/or zooplankton in the area and year concerned.

Overlap of Delta Smelt and *Eurytempora affinis*

Year	San Pablo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta	Total
1985				0	01	21031	1 83296				4338	0	0		0	308664
1986			2	71002	296837	49977	1399388				29757	0	0		0	2479806
1987				0	6369	0	1309980				23753	3986	0		0	1344087
1989				49	19458	0	0				0	0	0		0	19507
1990				0	0	0	0				0	0	0		0	0
1991				0	45	25	22611				0	0	0		0	22681
1992				8	0	140	0				0	0	0		0	148
1993			0	2633	0	0	0				0	0	0		0	2633
1994				0	0	0	0					0	0		0	0
1995				0	0	0	175					0	0			175
1996				0	0	0	0				0	0	0		0	0
1997				0	0	0	0				0	0	0			0
1998	0		0	0	0	0	0				0	0	0		0	0
1999	0			0	593	9659	0				0	0	0		0	10252
2000	0			0	2067	0	0				0	0	0		0	2067
2001	0			0	0	0	0					0	0		0	0
2002	0			0	0	0	1070				0	0	0		0	1070
2003	0			0	0	0	0				0	0	0		0	0
2004	0			0	0	0	0				0	0	0		0	0

Table C6 Continued.

Overlap of Delta Smelt and *Pseudiaptomus forbes*

Year	San Peblo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta	Total
1985				0	0	0	0				0	0	0		0	0
1986				0	0	0	0				0	0	0		0	0
1987				0	0	0	0				0	0	0		0	0
1989				27247	212569	0	1789186				0	0	0		10958	2039960
1990				12209	36410	90967	2761064				3 46126	33371	5101		0	3285247
1991				1735	12583	20091	8067233				2 28889	90396	0		0	8420926
1992				4928	01	55666	9 39044				1 18570	0	0		0	1218208
1993			202657	69951	352297	82951	3772163				1261535	0	0		0	6642094
1994				6974	8215	9761	2985739					0	6581		0	3017270
1995				2489453	171341	65805	32562					0	0			2704953
1996				69469	963862	70622	1034734				6 06000	0	0		0	2077212
1997				59269	02	16946	7 78120				71494	0	0			1125829
1998	0		656689	39822	261032	11324	52910				16530	0	0		0	1347285
1999	0			1574293	194067	1960043	3072642				2 20411	81353	0		0	7102809
2000	0			98221	5075952	73885	2976427				1 70856	0	0		0	4026984
2001	0			7540	1757	2867	2345362					0	0		0	2357526
2002	0			4030	0	12227	6 44972				66282	0	0		0	727511
2003	0			481	6141	84828	4 38564				34611	0	0		0	564625
2004	0			283	0	3886	33434				10093	0	0		0	47696

Table C6 Continued.

Overlap of Delta Smelt and *Acartiella sinensis*

Year	San Peblo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta	Total
1985				0	0	0	0				0	0	0		0	0
1986				0	0	0	0				0	0	0		0	0
1987				0	0	0	0				0	0	0		0	0
1989				0	0	0	0				0	0	0		0	0
1990				0	0	0	0				0	0	0		0	0
1991				0	0	0	0				0	0	0		0	0
1992				0	0	0	0				0	0	0		0	0
1993			0	0	0	0	0				0	0	0		0	0
1994				29252	4579	48382	4152783					0	0		0	4234996
1995				15240	0	0	805					0	0			16045
1996				86471	2772	89662	1 73575				0	0	0		0	352480
1997				6497	0	14322	1 49585				0	0	0			170404
1998	0		3322	24258	0	708	0				0	0	0		0	28288
1999	0			0	0	0	0				0	0	0		0	0
2000	0			0	0	0	13145				0	0	0		0	13145
2001	0			8791	244	2230	6 78693					0	0		0	689957
2002	0			1631	0	2973	1 46681				8721	0	0		0	160007
2003	0			189	649	50895	43498				2036	0	0		0	97266
2004	0			319	0	8993	57215				648	0	0		0	67175

Table C6 Continued.

Overlap of Delta Smelt and *Tortanus species*

Year	San Peblo Bay	Napa River	Carquinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	Lower Sac. River	Cache Slough	Upper Sac. River	Sac. Ship Channel	Lower SJ River	Near Franks Tract	East SE Delta	East Central Delta	SE Delta	Total
1985				0	0	0	0				0	0	0		0	0
1986				0	0	0	0				0	0	0		0	0
1987				0	0	0	0				0	0	0		0	0
1989				0	0	0	0				0	0	0		0	0
1990				0	0	0	0				0	0	0		0	0
1991				0	0	0	0				0	0	0		0	0
1992				0	0	0	0				0	0	0		0	0
1993			0	0	0	0	0				0	0	0		0	0
1994				4561	3069	0	0					0	0		0	7630
1995				55538	0	0	0					0	0			55538
1996				93596	0	11940	0				0	0	0		0	105536
1997				7618	0	0	0				0	0	0			7618
1998	0		1435311	00938	0	0	0				0	0	0		0	244469
1999	16229			42417	0	0	0				0	0	0		0	58646
2000	0		1	20952	1524	1189	0				0	0	0		0	123665
2001	0			48522	233	1912	0					0	0		0	50667
2002	0			16074	0	432	0				0	0	0		0	16506
2003	0			4011	491	4239	0				0	0	0		0	8741
2004	0			2496	0	4441	178				23	0	0		0	7139

Percentage of Adults Entrained at the Banks and Tracy Pumping Stations

Table C7 The calculation of the number of adult delta smelt entrained 1993 to 2005 at the Banks and Tracy water pumping facilities. The calculations shown here assume the following parameters: Banks Louver Efficiency = 0.75, Tracy Louver Efficiency = 0.15, Banks Forebay Volume = 30,000 acre feet, Tracy Forebay Volume =20 acre feet, Daily Survival Rate = exp(-0.025) = 0.9753.

		Salvage		Salvage Divided by Louver Efficiency		Export Rates (cfs)		Residence Time (Days)		Prescreen Survival		Estimated Entrainment	
Year	Month	Banks	Tracy	Banks	Tracy	Banks	Tracy	Banks	Tracy	Banks	Tracy	Banks	Tracy
1993	11	0	0	0	0	2595	4240	5.83	0.002	0.864	1.000	0	0
1993	12	88	0	117	0	6288	4144	2.41	0.002	0.942	1.000	125	0
1994	1	16	0	21	0	3496	2277	4.33	0.004	0.897	1.000	24	0
1994	2	54	120	72	800	1912	3870	7.91	0.003	0.821	1.000	88	800
1994	3	61	108	81	720	1921	2268	7.87	0.004	0.821	1.000	99	720
1994	4	0	0	0	0	336	1562	45.01	0.007	0.325	1.000	0	0
1994	5	0	0	0	0	707	1123	21.39	0.009	0.586	1.000	0	0
1994	11	0	0	0	0	3586	2488	4.22	0.004	0.900	1.000	0	0
1994	12	42	12	56	80	3903	3534	3.88	0.003	0.908	1.000	62	80
1995	1	1937	120	2583	800	7508	4141	2.01	0.002	0.951	1.000	2716	800
1995	2	457	24	609	160	4573	4218	3.31	0.002	0.921	1.000	662	160
1995	3	4	12	5	80	533	2372	28.38	0.004	0.492	1.000	11	80
1995	4	0	24	0	160	147	3326	102.89	0.003	0.076	1.000	0	160
1995	5	0	0	0	0	1279	2985	11.83	0.003	0.744	1.000	0	0
1995	11	0	0	0	0	1235	4223	12.25	0.002	0.736	1.000	0	0
1995	12	0	0	0	0	113	4273	133.85	0.002	0.035	1.000	0	0
1996	1	3109	1068	4145	7120	5707	4272	2.65	0.002	0.936	1.000	4429	7120
1996	2	846	444	1128	2960	2976	3589	5.08	0.003	0.881	1.000	1281	2960
1996	3	131	24	175	160	2735	739	5.53	0.014	0.871	1.000	201	160
1996	4	9	102	12	680	1801	2395	8.40	0.004	0.811	1.000	15	680
1996	5	0	0	0	0	2617	2074	5.78	0.005	0.865	1.000	0	0
1996	11	0	12	0	80	5834	4123	2.59	0.002	0.937	1.000	0	80
1996	12	6	12	8	80	3576	4083	4.23	0.003	0.900	1.000	9	80
1997	1	0	0	0	0	629	2022	24.05	0.005	0.548	1.000	0	0
1997	2	32	48	43	320	1706	557	8.87	0.018	0.801	1.000	53	320
1997	3	146	1584	195	10560	2577	4344	5.87	0.002	0.864	1.000	225	10561
1997	4	139	528	185	3520	1809	2719	8.36	0.004	0.811	1.000	228	3520

1997	5	2	0	3	0	1357	1744	11.15	0.006	0.757	1.000	4	0
1997	11	0	0	0	0	4916	4201	3.08	0.002	0.926	1.000	0	0
1997	12	257	24	343	160	6838	4075	2.21	0.003	0.946	1.000	362	160
1998	1	118	12	157	80	3195	3952	4.73	0.003	0.888	1.000	177	80
1998	2	0	24	0	160	234	2956	64.64	0.003	0.199	1.000	0	160
1998	3	8	584	11	3893	0	2062		0.005		1.000	0	3894
1998	4	0	48	0	320	17	1446	889.71	0.007	0.000	1.000	0	320
1998	5	0	0	0	0	909	2320	16.64	0.004	0.660	1.000	0	0
1998	6	0	36	0	240	2189	2862	6.91	0.004	0.841	1.000	0	240
1998	11	0	0	0	0	2191	2136	6.90	0.005	0.841	1.000	0	0
1998	12	16	0	21	0	2072	33	7.30	0.306	0.833	0.992	26	0
1999	1	4	24	5	160	1426	2978	10.61	0.003	0.767	1.000	7	160
1999	2	110	1356	147	9040	938	4317	16.12	0.002	0.668	1.000	219	9041
1999	3	124	440	165	2933	2948	4108	5.13	0.003	0.880	1.000	188	2934
1999	4	176	233.5	235	1557	3105	1710	4.87	0.006	0.885	1.000	265	1557
1999	5	0	0	0	0	1640	1703	9.22	0.006	0.794	1.000	0	0
1999	11	0	24	0	160	5185	4195	2.92	0.002	0.930	1.000	0	160
1999	12	66	60	88	400	3778	2544	4.00	0.004	0.905	1.000	97	400
2000	1	238	564	317	3760	6454	3205	2.34	0.003	0.943	1.000	336	3760
2000	2	5491	2328	7321	15520	7391	4108	2.05	0.003	0.950	1.000	7706	15521
2000	3	1663	1056	2217	7040	5554	3380	2.72	0.003	0.934	1.000	2374	7041
2000	4	210	516	280	3440	3048	2207	4.96	0.005	0.883	1.000	317	3440
2000	5	0	0	0	0	1713	1263	8.83	0.008	0.802	1.000	0	0
2000	11	64	240	85	1600	5316	4061	2.85	0.003	0.931	1.000	92	1600
2000	12	36	156	48	1040	4791	3910	3.16	0.003	0.924	1.000	52	1040
2001	1	25	156	33	1040	3929	2737	3.85	0.004	0.908	1.000	37	1040
2001	2	1662	2208	2216	14720	4734	3519	3.19	0.003	0.923	1.000	2400	14721
2001	3	390	1008	520	6720	5880	1883	2.57	0.005	0.938	1.000	555	6721
2001	4	0	276	0	1840	1724	2177	8.77	0.005	0.803	1.000	0	1840
2001	5	0	24	0	160	594	857	25.46	0.012	0.529	1.000	0	160
2001	11	0	0	0	0	3246	3756	4.66	0.003	0.890	1.000	0	0
2001	12	781	348	1041	2320	6119	3677	2.47	0.003	0.940	1.000	1108	2320
2002	1	3983	1248	5311	8320	6466	4145	2.34	0.002	0.943	1.000	5630	8321
2002	2	112	168	149	1120	4976	3604	3.04	0.003	0.927	1.000	161	1120
2002	3	141	84	188	560	3896	4182	3.88	0.002	0.908	1.000	207	560
2002	4	0	0	0	0	2114	2145	7.15	0.005	0.836	1.000	0	0
2002	5	0	0	0	0	677	857	22.34	0.012	0.572	1.000	0	0
2002	11	0	0	0	0	3139	3671	4.82	0.003	0.887	1.000	0	0
2002	12	2008	792	2677	5280	4165	3333	3.63	0.003	0.913	1.000	2932	5280

2003	1	7413	2136	9884	14240	5771	4262	2.62	0.002	0.937	1.000	10553	14241
2003	2	951	540	1268	3600	6385	4274	2.37	0.002	0.942	1.000	1345	3600
2003	3	15	468	20	3120	6216	4355	2.43	0.002	0.941	1.000	21	3120
2003	4	0	36	0	240	2578	1899	5.87	0.005	0.864	1.000	0	240
2003	5	0	0	0	0	983	1465	15.39	0.007	0.681	1.000	0	0
2003	11	0	0	0	0	3828	4324	3.95	0.002	0.906	1.000	0	0
2003	12	6	120	8	800	4278	4150	3.54	0.002	0.915	1.000	9	800
2004	1	3405	1189	4540	7927	6830	4358	2.21	0.002	0.946	1.000	4798	7927
2004	2	681	480	908	3200	6408	3968	2.36	0.003	0.943	1.000	963	3200
2004	3	1415	852	1887	5680	6888	4141	2.20	0.002	0.947	1.000	1993	5680
2004	4	0	0	0	0	2143	1956	7.06	0.005	0.838	1.000	0	0
2004	5	0	0	0	0	753	961	20.09	0.011	0.605	1.000	0	0
2004	11	0	0	0	0	3821	4285	3.96	0.002	0.906	1.000	0	0
2004	12	0	0	0	0	4281	3789	3.53	0.003	0.915	1.000	0	0
2005	1	1107	540	1476	3600	7778	4212	1.94	0.002	0.953	1.000	1550	3600
2005	2	281	72	375	480	4982	3885	3.04	0.003	0.927	1.000	404	480
2005	3	0	0	0	0	3616	3372	4.18	0.003	0.901	1.000	0	0
2005	4	0	0	0	0	3754	2114	4.03	0.005	0.904	1.000	0	0
2005	5	0	0	0	0	2015	1070	7.51	0.009	0.829	1.000	0	0