Analysis of Data From the Salmon Smolt Survival Experiments

Bryan F.J. Manly
Western EcoSystems Technology Inc.
bmanly@west-inc.com

Summary

The data analysed were 13 pairs of estimated survival rates for salmon smolt, derived from mark-recapture experiments. Each pair consisted of an estimated survival rate from Courtland (about 6.5 miles above the Delta Cross Channel) to Chipps Island (about 26.5 miles downstream of the Delta Cross Channel), and an estimated survival rate from Ryde (about 2.5 miles below the Delta Cross Channel) to Chipps Island. A comparison of the Courtland to Chipps Island estimated survival rate with the paired Ryde to Chipps Island estimated survival rate therefore gives a measure of the Courtland to Ryde survival rate at the time when the mark-recapture experiment took place.

The cross channel gates were open when nine of the 13 mark-recapture experiments took place, and closed on the other four occasions. The main interest for the data analysis was in the difference in smolt survival, if any, due to the gates being open or closed. A multiple linear regression model was constructed to account for the estimated survival rates in terms of effects due to the time when the experiments took place and whether the gates were open or closed. Without the gate effect included in the model it accounts for about 64% of the variation in the data. Adding a gate effect does not improve the fit in a significant way. The estimated effect of the gates being closed is 1.32 (i.e., the survival rate is multiplied by 1.32 compared to when the gates are open), but this is not significantly different from 1.00 and has a 95% confidence interval from 0.47 to 3.69. On this basis it is concluded that there is no evidence from these data that the survival of smolt is effected by the opening or closing of the gates.

Data

The data that I considered were the estimated survival rates for salmon smolt released at Courtland (about 6.5 miles above the Delta Cross Channel), and for salmon smolt released at Ryde (about 2.5 miles below the Delta Cross Channel). Ryde is also downstream of the Georgina Slough, which is another route by which smolts enter the central Delta. There are 13 pairs of these survival estimates, corresponding to releases from 1984 to 1988. On nine occasions the two cross channel gates were open, and they were closed for the other four occasions. Recaptures were at Chipps Island, about 24 miles downstream from Ryde.

Regression Model

Rather than looking at simple ratios, I constructed a regression model to account for the variation in the data. Considering first the estimated survival from Ryde to Chipps Island, I assumed that this may vary with time. The model that I used was therefore

$$\ln(S_{1i}) = \ln(\phi_i) + e_{1i}, \tag{1}$$

where S_{1i} is the ith Ryde to Chipps Island estimated survival rate, ϕ_i is the true survival rate at that time, and e_{1i} is the error of estimation. The reason for using logarithms here was to be able to relate the Ryde to Chipps Island survival rate to the Courtland to Chipps Island survival rate, as will now be explained.

The Courtland to Chipps Island survival rate is expected to be lower than the Ryde to Chipps Island survival rate because some smolt will not survive the passage from Courtland to Ryde. If it is assumed that the Courtland to Ryde survival rate is approximately constant at θ, then a model for the Courtland to Chipps Island estimated survival rate similar to that of equation (1) becomes

$$\ln(S_{2i}) = \ln(\theta\phi_i) + e_{2i},$$

or equivalently

$$\ln(S_{2i}) = \ln(\phi_i) + \ln(\theta) + e_{2i}, \tag{2}$$

where S_{2i} is the estimated Courtland to Chipps Island survival for the ith time period.

Equation (2) makes no allowance for the survival from Courtland to Ryde being affected by the gates being closed. This can be accounted for by assuming that when the two gates are open the survival rate from Courtland to Ryde is θ, but that if the gates are closed then this survival rate changes to $\theta\delta$. Equation (2) then becomes

$$\ln(S_{2i}) = \ln(\phi_i) + \ln(\theta) + G_i\ln(\delta) + e_{2i}, \tag{3}$$

where G_i = 1 if the gates are closed, but is otherwise 0.

Equations (1) and (3) can now be combined into a single regression equation for estimation purposes. This is

$$\ln(S_i) = \ln(\phi_i) + CR\{\ln(\theta) + G_i\ln(\delta)\} + e_i, \tag{4}$$

where S_i is an estimated survival rate for the ith time period, and CR = 0 if the estimate is for survival from Ryde to Chipps Island, or is 1 if the estimate is for Courtland to Ryde to

Chipps Island. Then if CR = 0 equation (4) is the same as equation (1), while if CR = 1 it becomes equation (3).

What this means in effect is that the logarithms of survival rates are related to (1) a general survival factor with 13 levels, $\ln(\phi_1)$, $\ln(\phi_2)$, ..., $\ln(\phi_{13})$, one for each time period, (2) a survival factor $\ln(\theta)$ for Courtland to Ryde, which only applies for the Courtland to Chipps Island estimates, (3), and a gates closed factor $\ln(\delta)$, which only applies for the Courtland to Chipps Island estimates when the gates are closed. The regression data can then be written as shown in Table 1. In that table Surv1 indicates the 13 levels of the general survival factor, Surv2 indicates the presence of absence of the Courtland to Ryde survival factor, and Gate indicates the presence or absence of the gate closed factor.

Results

The first model considered did not include an effect for the gates being closed. This gave a very significant fit (F = 4.38 with 13 and 12 df, p = 0.008), and accounted for 63.7% of the variation in the data. Adding in the gate effect did not give a significant improvement to the fit of the equation (F = 0.36 with 1 and 11 df, p = 0.563), and the percentage of variation in the data accounted for was reduced to 61.7%. This model therefore provides no evidence of any effect of the gates being closed.

The standardized residuals in Table 1 are the differences between the estimated survival rates and the values given by the fitted equation (4), divided by the estimated residual standard deviation, for the model including an effect for the gates being closed. In general, standardized residuals should mostly be within the range from -2 to +2, and almost always within the range from -3 to +3. On this basis there are two large standardized residuals. These are for the 24/6/1988 survival period, for which the survival estimate from Courtland to Chipps Island was very low (S = 0.02, ln(S) = -3.912) compared with the Ryde to Chipps Island survival estimate (S = 0.34, ln(S) = -1.079). Apart from these residuals, the model appears to give a reasonable fit to the data.

Table 2 shows the estimated parameters from the model. Of these, the Surv1 parameters are the ones that allow the Ryde to Chipps Island parameters to vary with time. The Surv2 parameter is the estimate of $\ln(\theta)$ in equation (4). This is equal to -0.664, and is significantly different from zero at the 5% level. The corresponding estimate of the survival from Courtland to Ryde is exp(-0.664) = 0.515.

The parameter Gate is the main one of interest. The estimate is 0.278, with a large standard error of 0.467. This estimate corresponds to $\ln(\delta)$ in equation (4), so the estimate of δ is exp(0.278) = 1.320. The estimate of $\ln(\delta)$ is not significantly different from zero (p = 0.563), so the estimate of δ is not significantly different from one. Using the t-distribution with 11 df, a 95% confidence interval for the true value of $\ln(\delta)$ is -0.749 to 1.306. The corresponding limits for δ are then exp(-0.749) = 0.473 to exp(1.306) = 3.691. It is very clear that the available data are not sufficient to determine the true value of this parameter with any accuracy.

Table 1 The regression data, fitted values for the logarithms of survival rates from the regression analysis (Fit), standardized residuals from the regression (Std Res), and the fitted estimates of survival rates.

Date	Surv	LogS	Surv1	Surv2	Gate	Fit	Std Res	Fitted Survival
16/05/1983	1.39	0.329	1	0	0	0.46	-0.38	1.58
16/05/1983	1.22	0.199	1	1	1	0.07	0.38	1.07
11/06/1984	0.73	-0.315	2	0	0	-0.00	-0.85	1.00
11/06/1984	0.70	-0.357	2	1	0	-0.67	0.85	0.51
10/05/1985	0.77	-0.261	3	0	0	-0.34	0.21	0.71
10/05/1985	0.34	-1.079	3	1	0	-1.00	-0.21	0.37
27/05/1986	0.68	-0.386	4	0	0	-0.36	-0.08	0.70
27/05/1986	0.37	-0.994	4	1	0	-1.02	0.08	0.36
28/04/1987	0.84	-0.174	5	0	0	-0.10	-0.21	0.90
28/04/1987	0.66	-0.416	5	1	1	-0.49	0.21	0.61
01/05/1987	0.88	-0.128	6	0	0	-0.18	0.14	0.84
01/05/1987	0.41	-0.892	6	1	0	-0.84	-0.14	0.43
03/05/1988	0.93	-0.073	7	0	0	-0.04	-0.11	0.96
03/05/1988	0.68	-0.386	7	1	1	-0.42	0.11	0.66
06/05/1988	1.27	0.239	8	0	0	0.29	-0.15	1.34
06/05/1988	0.73	-0.315	8	1	0	-0.37	0.15	0.69
21/06/1988	0.40	-0.916	9	0	0	-1.15	0.70	0.32
21/06/1988	0.17	-1.772	9	1	1	-1.54	-0.70	0.22
24/06/1988	0.34	-1.079	10	0	0	-2.16	2.96	0.11
24/06/1988	0.02	-3.912	10	1	0	-2.83	-2.96	0.06
02/05/1989	1.20	0.182	11	0	0	0.34	-0.42	1.40
02/05/1989	0.84	-0.174	11	1	0	-0.33	0.42	0.72
02/06/1989	0.48	-0.734	12	0	0	-0.56	-0.47	0.57
02/06/1989	0.35	-1.050	12	1	0	-1.22	0.47	0.29
15/06/1989	0.16	-1.833	13	0	0	-1.34	-1.34	0.26
15/06/1989	0.22	-1.514	13	1	0	-2.01	1.34	0.13

Discussion

The above analysis assumes that all of the original survival rates estimated by mark-recapture methods are about equally reliable, i.e. have about the same variance. It is possible that this is not the case because of variation in the number of marked and/or recovered fish. Different variances could be allowed for in the regression analysis, but it seems unlikely that this would change the results much.

The analysis makes it possible to estimate the effect of closing the Delta Cross Channel gates in terms of a factor that multiplies the survival rate from Courtland to Ryde. This estimated factor is not significantly different from 1.0, and the 95% confidence interval for the true value of the factor is 0.47 to 3.69. The main conclusion from the analysis described here is therefore that there is no statistically significant effect of closures of the Delta Cross Channel on the survival of smolt.

Table 2 Parameter estimates for the fitted regression model.

Parameter[1]	Estimate	Std Err	t-value	p-value[2]
Constant	0.4566	0.4342	1.05	0.315
Surv1 2	-0.4608	0.5967	-0.77	0.456
Surv1 3	-0.7948	0.5967	-1.33	0.210
Surv1 4	-0.8148	0.5967	-1.37	0.199
Surv1 5	-0.5590	0.5492	-1.02	0.331
Surv1 6	-0.6348	0.5967	-1.06	0.310
Surv1 7	-0.4935	0.5492	-0.90	0.388
Surv1 8	-0.1628	0.5967	-0.27	0.790
Surv1 9	-1.6080	0.5492	-2.93	<u>0.014</u>
Surv1 10	-2.6204	0.5967	-4.39	<u>0.001</u>
Surv1 11	-0.1208	0.5967	-0.20	0.843
Surv1 12	-1.0169	0.5967	-1.70	0.116
Surv1 13	-1.7984	0.5967	-3.01	<u>0.012</u>
Surv2	-0.6636	0.2589	-2.56	<u>0.026</u>
Gate	0.2783	0.4667	0.60	0.563

[1]The parameter Surv1 1 (for the survival from Ryde to Chipps Island for the first time period) is set to zero in order to fix the other parameter values for this factor.
[2]Coefficients that are significantly different from zero at the 5% level are underlined.