An alternative analysis of Delta Action 8 Chinook Salmon Studies

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November 28, 2006

Summary

A hierarchical model, which allows for (1) between year variation in underlying survival and capture probabilities and (2) within year sampling variation, is used to analyze the Delta Action 8 studies data in a Bayesian framework. The method overcomes several limitations of previous analyses. Based on the fitted model, there is a 95% probability that the association between exports and juvenile survival is negative.

1 Previous analyses

The Delta Action 8 studies objective is to quantify the relationship between export levels and the survival of outmigrating juvenile Chinook salmon.

Paired Release-Recovery Design:

1. CWT and fin clip hatchery reared juvenile Chinook salmon;
2. Release pairs of groups into Georgiana Slough and at Ryde;
3. Recover at Chipps Island and in ocean fisheries.

Methods:

1. Calculate Georgiana Slough and Ryde survival *indices* based on Chipps Island recoveries or ocean fisheries recoveries, *separately*. For example,

$$I_{GS \rightarrow Chipps} = \frac{Recs_{GS \rightarrow Chipps}}{Rel_{GS} * f}$$

   where f is a measure of trawl efficiency.

2. Divide the indices to get a relative survival index, e.g.,

$$Ratio_{GS/Ryde} = \frac{I_{GS \rightarrow Chipps}}{I_{Ryde \rightarrow Chipps}}.$$

3. Regress the relative survival index against export levels:

$$Ratio_{GS/Ryde} = \beta_0 + \beta_1 Exports + \epsilon.$$

Limitations:

1. Trawl efficiency measure, f, is likely biased and likely imprecise.
2. Separate analysis of Chipps Island and ocean recoveries is statistically inefficient.
3. Sampling variation in indices is ignored.
4. The ratio of survival probabilities likely varies between years (and potentially between release pairings made in the same year) as water conditions and fish condition vary. This between year variation is ignored in the analyses.
5. The analysis is a two-stage procedure, estimate survival ratios using observed data and then regress the estimated ratios against export levels. Integrated procedures that directly model observed data as a function of exports will generally be more statistically efficient, i.e., have smaller standard errors.

2 Alternative analysis: Bayesian hierarchical model

The method used addresses each of the limitations of previous analyses: (1) trawl efficiency measures are not calculated; (2) Chipps Island and Ocean fishery recoveries are analyzed jointly; (3) sampling variation in indices is accounted for; (4) between year variation in survival (and capture) probabilities are accounted for; (5) analysis of the relationship between survival and exports is done in an integrated way.

There are three levels to the hierarchical model:

Level 1—Recoveries, y's, as a function of recovery (survival+capture) probabilities.

$$y_{GS\to CI}, y_{GS\to Oc} \sim \text{Trinomial}\left(R_{GS}, \theta r_{Ry\to CI}, r_{Ry\to Oc}\right) \quad (1)$$
$$y_{Ry\to CI}, y_{Ry\to Oc} \sim \text{Trinomial}\left(R_{Ry}, r_{Ry\to CI}, r_{Ry\to Oc}\right). \quad (2)$$

Level 2—Variation in recovery probabilities, and survival as a function of exports.

$$logit(\theta) \sim \text{Normal}\left(\beta_0 + \beta_1 Exports, \sigma^2_\theta\right) \quad (3)$$
$$logit(r_{Ry\to CI}) \sim \text{Normal}\left(\mu_{r_{Ry\to CI}}, \sigma^2_{r_{Ry\to CI}}\right) \quad (4)$$
$$logit(r_{Ry\to Oc}) \sim \text{Normal}\left(\mu_{r_{Ry\to Oc}}, \sigma^2_{r_{Ry\to Oc}}\right) \quad (5)$$

Level 3—Prior distributions for parameters of Level 2.

$$\beta_0 \sim \text{Normal}\left(0, 1.0E-6\right) \quad (6)$$
$$\beta_1 \sim \text{Normal}\left(0, 1.0E-6\right) \quad (7)$$
$$\mu_{Ry\to CI} \sim \text{Normal}\left(-6, 1.0E-6\right) \quad (8)$$
$$\mu_{Ry\to Oc} \sim \text{Normal}\left(-4, 1.0E-6\right) \quad (9)$$
$$\sigma_\theta^{-2}, \sigma^{-2}_{r_{Ry\to CI}}, \sigma^{-2}_{r_{Ry\to Oc}} \sim \text{Gamma}\left(0.001, 0.001\right) \quad (10)$$

3 Results

First, a "robustness" of results evaluation:

Table 1: Bayesian and Classical results contrasted.

	Posterior θ		Classical $\hat{\theta}$		Ratio of
Year	Mean	Std Dev	MLE	Std Error	Survival Indices
1994	0.27	0.033	0.27	0.032	0.14
1995	0.35	0.095	0.33	0.098	0.27
1995	0.37	0.042	0.37	0.043	0.16
1996	0.52	0.052	0.52	0.053	0.26
1998	0.13	0.041	0.11	0.039	0.05
1998	0.84	0.062	0.88	0.081	0.28
1999	0.62	0.061	0.61	0.061	0.24
1999	0.67	0.070	0.67	0.073	0.72
1999	0.27	0.045	0.26	0.044	0.16
2000	0.72	0.071	0.73	0.078	0.67
2000	0.33	0.025	0.33	0.024	0.31
2003	0.29	0.045	0.28	0.044	0.04
2004	0.28	0.048	0.28	0.048	0.28
2005	0.35	0.240	0.25	0.226	0.32

Next, the relationship between exports and the survival ratio, θ, is a function of the slope coefficient β_1 in Equation 3. β_1=0 that indicates no relationship between θ and exports, while $\beta_1 < 0$ indicates a negative relationship, as exports increase, the Georgiana Slough survival probability relative to the Ryde survival probability decreases.

Table 2: Posterior distribution statistics for θ in the hierarchical model for DA 8 studies.

Parameter	Mean	0.025	0.05	0.50	0.95	0.975
β_1	-0.555	-1.177	-1.057	-0.548	-0.070	0.037

Figure 1: Estimated survival ratios (non-hierarchical model) for DA-8 studies plotted against export levels. Weighted regressions were used for all three models fit, with the weights being the inverse of the standard errors squared. The nonparametric regression of the late fall data used the supersmoother function in R.