

## **Submission 17**

### **Testing the Regime Shift Extra Mortality Hypothesis**

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#### **Abstract**

The climate regime-related extra mortality hypotheses was put forth in the prospective analysis of PATH to represent the scientific hypothesis that there is certain low-frequency climate-related mortality that occurs after spring/summer chinook smolts fish clear the hydro-system. To test this hypothesis, we examined the historical data for a shift downward in post-Bonneville survival of fish that migrated in-river corresponding to the 1977 regime shift (brood year 1975). We found no statistically significant shift in in post-Bonneville survival using the FLUSH passage model with either life cycle model (Alpha or Delta). Using the CRiSP passage model, there was a significant downward shift in the logarithm of post-Bonneville survival corresponding to the 1977 regime shift (0.966 and 1.224 for the Delta and Alpha models, respectively). Using FLUSH there was a small nonsignificant downward shift (0.01 and 0.33 for the Alpha and Delta models, respectively). This explains why, using FLUSH, the regime shift hypothesis gives essentially the same results as the BKD extra mortality hypothesis (or the hydro-related extra mortality hypothesis when it is properly framed mathematically). Using the CRiSP passage model there was a large and significant shift in post-Bonneville survival corresponding to the 1977 regime shift. Since the prospective effect of a regime shift is keyed on the retrospective estimate of the 1977 shift, the large shift estimated using CRiSP leads to a large increase Post-Bonneville survival when there are changes to a favorable climate regime in the future.

## **Introduction**

Widespread ecological changes related to interdecadal climate variations in the Pacific have been observed in this century. Dramatic shifts in many marine and terrestrial ecological variables in western North America coincided with changes in the physical environment in the late 1970s (about 1977). The 1977 regime shift is not unique in the climate record nor in the record of North Pacific salmon production. Signatures of an interdecadal climate variability are detectable in many Pacific basin ecological systems (Mantua et al. 1997). Among the salmon species shown to have interdecadal variability were Alaskan sockeye, Alaskan pink salmon, Columbia River spring chinook, and Washington-Oregon-California coho. While the climate regime from 1977-present has favored Alaskan sockeye and pink salmon production, it has been associated with decreased production of Columbia River spring chinook and WOC coho (Hare et al. 1998).

The Pacific Decadal oscillation is an index of climate based on the North Pacific sea surface temperature pattern since 1900. It is an index that other physical and biological tend to follow on the interdecadal time scale. The signature of Pacific Decadal oscillation appears in the Gulf of Alaska Air Temperature, British Columbia coastal sea surface temperature, Scripps Pier sea surface temperature, Gulf of Alaska stream flow, and British Columbia/Washington stream flow. It also appears in other measures of climate such as the North Pacific sea level pressure.

A regime shift occurs every 25-30 years, whenever the Pacific Decadal oscillation makes a polarity switch (positive to negative or visa versa). The Bayesian Simulation Model simulates the Pacific Decadal oscillation using a square wave with a period of 60 years (Marmorek and Peters 1998). In this century, the polarity switches occurred in 1925 (to warm/dry climate), 1947 (to cold/wet climate), and 1977 (to warm/dry climate). These years correspond to Minobe's (1997) analysis of reconstructed continental surface temperatures, which showed interdecadal oscillations (of period 50-70 years) over the last

3 centuries. The next polarity switch is modeled in the Bayesian Simulation Model to occur in 2007 (spring chinook brood year 2005).

The biological effects of these regime shifts have been dramatic, changes in catch of Alaskan pink and sockeye salmon decreased by about 57% in 1947, and increased by about 230% during the 1977 climate regime shift (See Table 1.0 below). Generally speaking Alaskan salmon and Pacific Northwest salmon have run sizes that fluctuate in reverse to one another (Hare et al. 1998). The 1947 shift, which was bad for Alaskan stocks, was good for Columbia River upriver spring chinook, which showed a 49.1% increase.

The 1977 regime shift, though good for Alaskan stocks, was bad for Columbia River upriver spring chinook, which showed a 55.5% decrease (See Figure below).

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Table 1.0. Percent change in mean catch of four Alaskan stocks and run size of Columbia River upriver spring chinook following major Pacific Decadal Oscillation polarity changes in 1947,1977. Mean catch level (run size for Columbia stock) were estimated from intervention models fitted to the data, using a 1-year lag for both pink salmon stocks, and 2-year lag for western sockeye, and a 3-year lag for central sockeye, and a 2-year lag for spring chinook. (Alaskan stocks from Mantua et al. [1997]).

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<b>Salmon stock</b>	<b>1947 step</b>	<b>1977 step</b>
Western Alaskan sockeye	-32.2%	+242.2%
Central Alaskan sockeye	-33.3%	+220.4%
Central Alaskan pink	-38.3%	+251.9%
Southeast Alaskan pink	-64.4%	+208.7%
C.R. upriver spring chinook (run size)	+49.1%	-55.5%

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In this paper, we tested whether a climate regime shift is evident in the estimates of extra mortality derived by the passage models in conjunction with both life cycle

models, which use spawner-recruit data from brood years 1952-1990. We found that using the CRiSP passage model, there was a significant downward shift in post-Bonneville survival corresponding to the 1977 regime shift, but using FLUSH there was not.

## Methods

### *The Delta Life-Cycle Model*

For the Delta life cycle model, the estimation of the extra mortality proceeds as in Marmorek and Peters (1998). The delta model was developed for the analysis of the spawner-recruit data of brood years 1952-1990 (Deriso et al., 1996). It includes a measure of the mortality of the seven Snake stocks, compared to the six lower Columbia stocks;  $\mathbf{m}$  a year-effect,  $\mathbf{d}$  which represents common annual fluctuations in recruitment for all 13 stocks; a stock specific, density-independent Ricker-a term; and a stock-specific, density-dependent Ricker-b parameter. The model, treated in detail in other PATH documents, is summarized below (Deriso et al. 1996).

$$\log(R_{t,i}) = \log(S_{t,i}) + a_i - b_i S_{t,i} - \mathbf{m}_t - n_{t,i} X + \mathbf{d}_t + \mathbf{e}_{t,i} \quad [1]$$

Where:

$R_{t,i}$	=	Columbia River “observed” returns (recruitment) originating from Spawning in year $t$ and stock $i$
$S_{t,i}$	=	“observed” spawning in year $t$ and stock $i$
$a_i$	=	Ricker-a parameter, which depends on stock
$b_i$	=	Ricker-b parameter, which depends on stock
$\mathbf{m}_t$	=	Differential mortality in year $t$
$n_{t,i}$	=	Number of first level dams (X-dams) stock $i$ must pass in year $t$
$X$	=	Dam passage mortality per first level dam
$\mathbf{d}_t$	=	Common year effect for year $t$

$\mathbf{e}_{i,t}$  = normally distributed mixed process error and recruitment measurement error term  $N(0, V\mathbf{e})$  (i.e., it follows a normal distribution with mean zero and variance  $V\mathbf{e}$ )

For each year of the retrospective study, we estimate the total mortality,  $m$ , which includes both passage and extra mortalities, by using the maximum likelihood estimates of  $\mathbf{m}$  and  $X_t$ .

$$m_t = \mu_t + n_t X \quad [2]$$

The estimate of the post-Bonneville survival factor for in-river migrants is then

$$\mathbf{I}_{n,t} = \exp(-m_t) / \mathbf{w}_t \quad [3]$$

where  $\mathbf{w}_t$  is the system survival supplied by the passage models for each year (1952-1990). It is defined as

$$\mathbf{w}_t = \exp(-M_t)(D_t P_t + 1 - P_t)$$

where  $\exp(-M_t)$  is the estimate of passage survival to the tailrace of Bonneville Dam,  $D_t$  is the ration of post-Bonneville survivals of transported and non-transported fish, and  $P_t$  is the proportion of fish surviving to the Bonneville tailrace that were transported.

The time series of  $\log(\mathbf{I}_n)$  estimates for the CRiSP and FLUSH models is shown in Figure 1.

In the prospective analyses of the regime shift hypotheses, the future values of  $\mathbf{I}_n$  were chosen from the 1952-1974 retrospective values during a favorable climate regime and from the 1975-1990 during an unfavorable climate regime. We tested the regime shift by testing for a downward shift in the mean post-Bonneville survival factor between the periods 1952-1974 and 1975-1990 using a simple two-sample t-test.

#### *The Alpha Life-cycle Model*

Like the Delta model, the Alpha model uses a Ricker spawner-recruit relationship. However, it does not rely upon comparisons of upriver and downstream stock productivities to derive a differential mortality estimate that is assumed to bound the total

(passage + extra) mortality. Instead, it uses the estimates of passage mortality directly in the retrospective model. The Alpha model is of the form:

$$\log(R_{t,i}) = \log(S_{t,i}) + a_i - b_i S_t - M_{t,i} - \mathbf{a}_t + \mathbf{e}_{t,i} \quad [4]$$

Where:

- $R_{t,i}$  = Columbia River “observed” returns (recruitment) originating from Spawning in year  $t$  and stock  $i$
- $S_{t,i}$  = “observed” spawning in year  $t$  and stock  $i$
- $a_i$  = Ricker-a parameter, which depends on stock
- $b_i$  = Ricker-b parameter, which depends on stock
- $\mathbf{a}_t$  = Common additional mortality in year  $t$  for all upriver (Snake) stocks (sums to zero over 1952-1990).
- $M_{t,i}$  = Passage mortality for stock  $i$  in year  $t$ . (Supplied by passage models)
- $\mathbf{e}_{t,i}$  = normally distributed mixed process error and recruitment measurement error term  $N(0, V\mathbf{e})$  (i.e., it follows a normal distribution with mean zero and variance  $V\mathbf{e}$ )

In the alpha model, the series of additional mortalities is described by a linear relationship with further explanatory variables. The retrospective alpha series is modeled in the Bayesian Simulation Model is as follows:

$$\mathbf{a}_t = \mathbf{b}'_1(1/F_t) + \mathbf{b}'_2(E_t/F_t) + \mathbf{b}'_3 Step_t - \log(D_t P_t + 1 - P_t) + \mathbf{b}'_0 \quad [5]$$

Where

- $\mathbf{b}'_j$  = Regression coefficients. The coefficient  $\mathbf{b}'_0$  is chosen so that the alpha series sums to zero over brood years 1952-1990. This ensures that the  $a_i$  represents the average productivity of stock  $i$  in the absence of passage mortality.
- $F_t$  = Average Flow (in KCFS) at Astoria for year  $t$  during April-June.
- $E_t$  = Climate index variable (PAPA drift). Represents the latitude of a drifting object after three months drift starting at station PAPA.
- $Step_t$  = Step is a factor variable that takes the value zero prior to 1975, and the estimated value STEP afterwards. It is formulated to model the

		effect of a 1975 (brood year) regime shift.
$D_t$	=	Ratio of post-Bonneville transport survival to post-Bonneville in-river survival for year $t$ .
$P_t$	=	Proportion of fish arriving below Bonneville that were transported for year $t$ .

*The Regime-shift extra mortality Hypothesis (Alpha Model)*

The prospective formulation of the regime shift-related extra mortality hypothesis using the alpha model specified a relationship between the estimate of the step function,  $Step_t$ , (which really models a regime shift). As before  $I_n$  represents the post-Bonneville survival factor for in-river fish.

The retrospective estimate of  $I_n$  is

$$I_n = \exp(-Step_t). \quad [6]$$

For convenience,  $I_n$  is set to one prior to 1975, and afterwards, its estimate is equal to  $\exp(-STEP)$ , where STEP is the 1975-1990 level of the factor variable  $Step_t$ . We can do this without loss of generality because it is only the *change* in post-Bonneville survival that we wish to estimate. These definitions supply us with the level STEP which is an estimate of the shift in the mean log(post-Bonneville Survival factor). We use its estimate and standard error to test the regime shift hypothesis. When the value of STEP is positive, it tends to support the regime shift hypothesis. Therefore we test the null hypothesis  $H_0: STEP=0$  (no change in Post-Bonneville survival factor) against the alternative hypothesis  $H_1: STEP > 0$ .

**Results**

*Delta Model Results*

Using CRiSP with the delta model there is a large significant downward shift in mean post-Bonneville survival in brood year 1975. Using the FLUSH passage there is no significant shift, and it is indeed small (Table 2.0). Thus, using the CRiSP passage model, we reject the null hypothesis that there was no downward shift in mean log(post-Bonneville survival), but using FLUSH, we fail to reject the null hypothesis. This result explains why the Regime-shift extra mortality hypothesis gives roughly the same

probabilities of jeopardy standards as the BKD extra mortality hypothesis when using FLUSH.

**Table 2.0** Regime shift hypothesis tests using the Delta Model. (n.s. = not significant at 0.05 level).

Passage Model	Change in $\log(I_n)$	d.f.	t-value	p-value
CRiSP	-0.9662	37	-4.702	0.00
FLUSH	0.0020	37	0.011	0.50 (n.s.)

*Alpha Model Results*

Like the Delta model, the Alpha model also gave different results of the hypothesis tests for the two passage models CRiSP and FLUSH. With CRiSP, there is a large and significant downward shift in the log of post-Bonneville survival of in-river fish, and with FLUSH there is a small, nonsignificant downward shift (Table 3). The magnitudes of the shifts in log post-Bonneville survival of in-river fish estimated by the Alpha and Delta models (for a given passage model) are roughly similar. CRiSP gives an estimate near 1.0 , and FLUSH, an estimate near 0.

**Table 3.0** Regime Shift Hypothesis tests using the Alpha Model (n.s.=not significant at the 0.05 level).

Passage Model	STEP estimate	d.f.	t-value	p-value
CRiSP	1.224	230	5.344	0.00
FLUSH	.332	230	1.53	0.06 (n.s.)

## **Discussion**

We tested whether a climate regime shift is evident in the estimates of extra mortality derived by the passage models in conjunction with both life cycle models, which use spawner-recruit data from brood years 1952-1990. We found that using CRiSP, there was a significant downward shift in log post-Bonneville survival corresponding to the 1977 regime shift (0.966-1.224), but using FLUSH there was a small nonsignificant shift (0.01- 0.33). This occurs because, in FLUSH, the loss in productivity of the Snake stocks starting in the 1970s is explained by a decrease in direct passage survival, while in CRiSP, it is not. Given these results, it is clear why the regime shift extra mortality hypothesis using FLUSH gives prospective results similar BKD extra mortality hypothesis. The shift in post-Bonneville survival of in-river fish in 1975 is weak, so in the future, there will be little benefit of a favorable climate regime shift. The opposite is true with CRiSP -- a favorable climate shift yields a large increase in log post-Bonneville survival.

## References:

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(See

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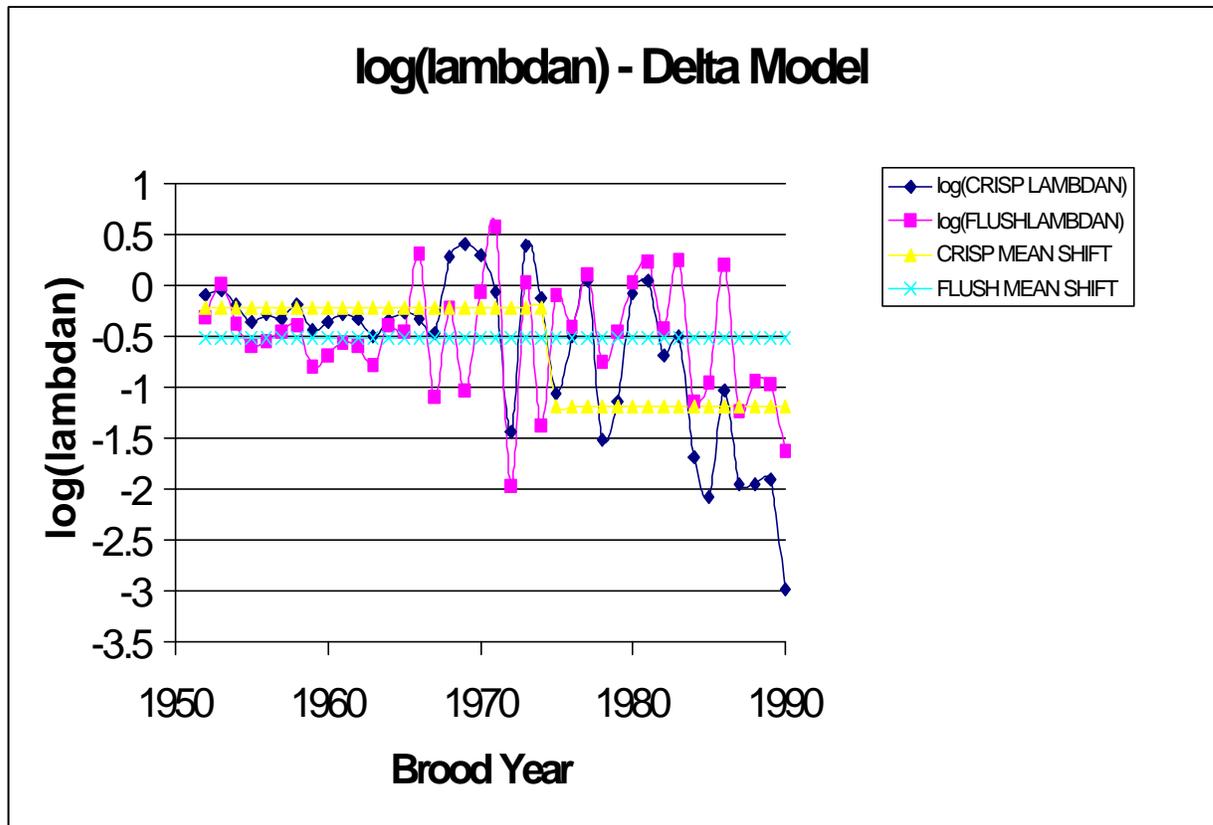
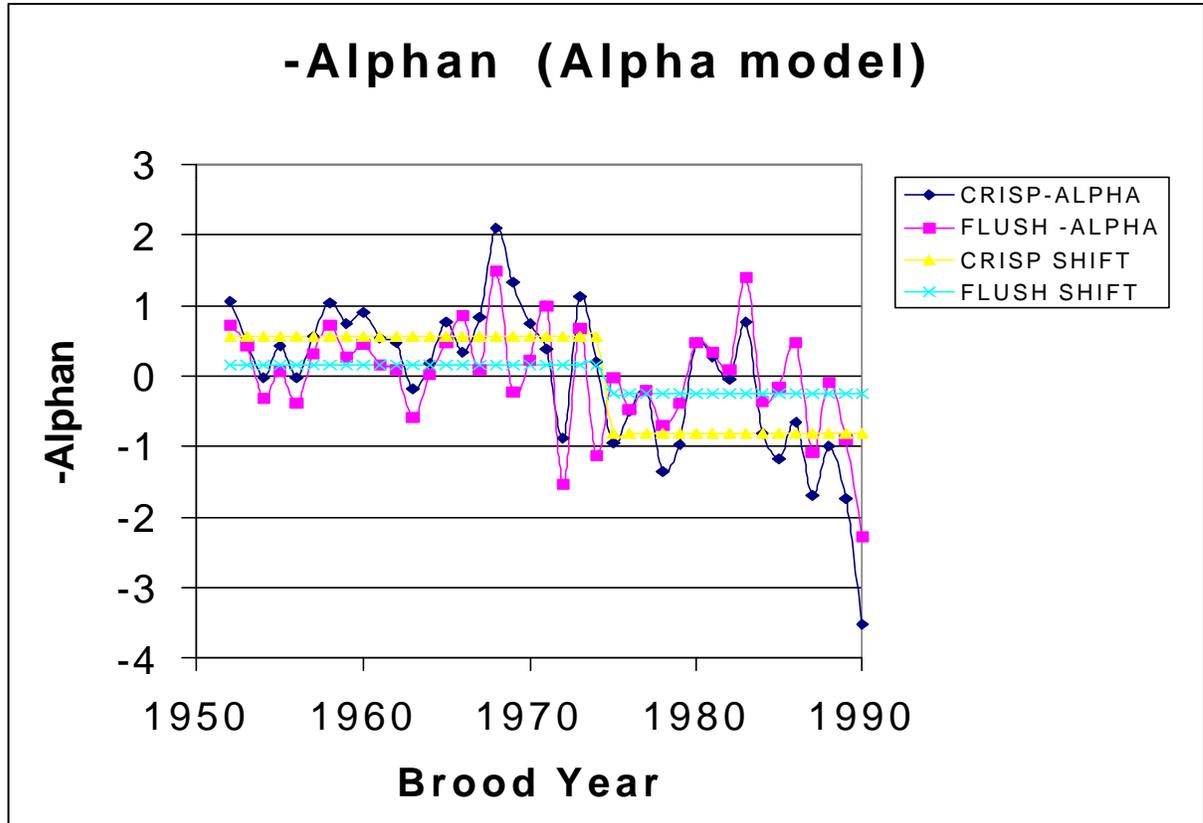


Figure 1. The time series of  $\log(l_n)$  estimates for the Delta model. Notice the large downward shift in post-Bonneville survival for CRiSP is absent using FLUSH



**Figure 2.** The time series of centered year effects from the alpha model (a separate year effect was estimated for each year), where the alpha series is adjusted to reflect the post-Bonneville survival of fish that migrated in-river. Like the delta model, the alpha model shows a larger shift corresponding to the 1975 (brood year) climate regime shift using the CRiSP model than using the FLUSH model.