Testing the Hydro-Related Extra Mortality Hypothesis

Richard A. Hinrichsen and Charles Paulsen

Wednesday, June 10, 1998

Abstract

The hydro-related extra mortality hypotheses was put forth in the prospective analysis of PATH to represent the notion that there is hydro-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 relationship between extra mortality (mortality that occurs after the smolts are clear of the hydro system) and in-river mortality (mortality experienced in the hydro-system). We discovered that the hypothesis, as formulated in the Delta life-cycle model analysis, was untestable because a different relationship was allowed for each year (1975-1990). To make the hypothesis testable, we reformulated it while keeping its scientific meaning intact. We also reformulated the hydro-related extra mortality hypothesis for the Alpha life-cycle model to allow for a test of the year-to-year variation between extra mortality and in-river mortality. We found that there was no statistically significant relationship between the retrospective estimates of extra mortality and mortality of in-river fish for either passage model (CRiSP and FLUSH), for either life-cycle model (Alpha and Delta), during either of the two periods examined: (1952-1990 and 1975-1990). The hydro hypothesis is an important determinant of whether actions meet the jeopardy and recovery standards, and therefore the selection of weight for this hypothesis will also be important. The tests we conducted are critical in determining how strongly the hypothesis should be weighted. This hypothesis needs to be given a low weight (perhaps zero) or reformulated to reflect the weak relationship between mortality experienced by smolts after they clear the hydro-system and in-river survival.

Introduction

The Hydro-related extra mortality hypotheses, was put forth to reflect the scientific belief that the mortality of Snake river spring and summer chinook after the fish are clear of the hydrosystem (extra mortality) is positively related to the in-river mortality. There are scientific reasons to believe that such a relationship may exist, both with smolts that migrate in-river, and for those that are transported (Marmorek and Peters 1998, pages 95-101). Among these are increased vulnerability to disease outbreak due to stress and injury (Mundy *et al.* 1994; Raymond 1988; Williams 1989), and increased vulnerability to other stressors, including predation by northern squawfish (Mundy *et al.* 1994). In the PATH preliminary decision analysis document, however, there was no demonstration of such a relationship with the retrospective spawner-recruit and passage model results. This information is readily available from the retrospective analyses and is conspicuously absent from discussion, so we present it here.

As the hydro-related extra-mortality hypothesis was actually stated, it was untestable with retrospective data, meaning that the hypotheses could not be falsified. This occurred because a different relationship between extra and in-river mortality was allowed for each retrospective water year (1975-1990). This meant that one parameter estimate was needed for each observation -- clearly an over-specified statistical model.

We remedied this difficulty by reformulating the hypothesis in a straightforward way that captured the essence of the scientific belief that there is a positive relationship between the extra mortality and passage mortality of fish migrating in-river. There was no statistically significant relationships between extra mortality of in-river migrants and their in-river mortality using either passage model (CRiSP or FLUSH). Thus we failed to reject the null hypothesis of no hydro-related extra mortality of in-river fish.

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; m, a year-effect, 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).

$$\log(R_{t,i}) = \log(S_{t,i}) + a_i - b_i S_t - m_t - n_{t,i} X + d_t + e_{t,i} \qquad [1]$$

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
	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
	d_t	=	Common year effect for year t
	$e_{t,i}$	=	normally distributed mixed process error and recruitment measurement error term N(0,Ve) (i.e., it follows a normal distribution with mean zero and variance Ve)

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 m_t and X_t.

$$m_t = m_t + n_t X \qquad [2]$$

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

$$l_{n,t} = \exp(-m_t)/w_t \qquad [3]$$

where w_t is the system survival supplied by the passage models for each year (1952-1990). The time series of l_n estimates for the CRiSP and FLUSH models is shown in Figure 1.

The remaining information needed to test the hydro hypothesis are the in-river survivals, $V_{n,t}$. This information is output from the passage models for each year (1952-1990). They represent the yearly in-river passage survival of smolts passing in-river (Marmorek and Peters, 1998, page 88 of Appendix A).

The Hydro-related extra mortality Hypothesis (Delta Model)

In the prospective analyses of the hydro-related hypotheses, a relationship is expressed between the future values of post-Bonneville survival of in-river migrants and in-river survivals by using retrospective survival estimates. As implemented, the relationship is as follows

$$(1-l_{n,t,y})/(1-V_{n,t,y})=(1-l_{n,t,r})/(1-V_{n,t,r}) \qquad [5]$$

where the *r* subscript denotes a retrospective estimate and the *y* subscript, a prospective estimate. During prospective simulations, the values of $l_{n,t,r}$ and $V_{n,t,r}$ are chosen at random from the retrospective brood years 1975-1990 in such a way that the prospective and retrospective unregulated flows are similar . In essence, there are exactly 16 different relationships (one for each year in 1975-1990) between the prospective post-Bonneville survival of in-river migrants and prospective in-river survival, namely,

$$(1-l_{n,t,y})=slope_{wt,r}\,(1-V_{n,t,y}), \qquad [6]$$

where $slope_{wt,r}$ is the slope of the linear relationship produced by retrospective water year *wt*: $slope_{wt,r}=(1-l_{n,wt,r})/(1-V_{n,wt,r})$. (Here the actual water year is lagged by 2 to match the brood year). During prospective simulations, the each slope will vary about its estimate according to its posterior distribution

Testing the Hypotheses with retrospective estimates (Delta Model)

To weight this extra mortality hypothesis properly, one would want to know whether this prospective relationship was supported by the retrospective data. Ideally, one would be able to apply the relationship to the retrospective data and determine how well it fit. However, the relationship requires estimation of 16 parameters (the slopes in equation [6]), for fitting 16 observations of V_n and l_n (1975-1990), making a statistical test impossible. To make hypotheses testable we used a simple linear regression model with V_n as the explanatory variable and l_n as the dependent variable. This allows us to test for correspondence between V_n and l_n.

$$l_{n,t} = b_0 + b_1 V_{n,t} + e_t \qquad [7]$$

We could have formulated this model so that the dependent variable was $(1-l_{n,t})$ and the independent variable, $(1-V_{n,t})$ as in the original formulation, but the conclusions of the regressions will not be affected by this variable transformation. We also believed that the graphs and regressions would be simpler to interpret using this alternative formulation.

What we wish to test here is the hypotheses that the post-Bonneville survival of in-river migrants is related to in-river survival. We test the null hypotheses that b_1=0 against the hypotheses that b_1 is positive. In order to conduct a single test for each passage model and each set of years (1952-1990 and 1975-1990), we used the average values of $V_{n,t}$, w_t reported from the passage modeling groups.

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 downriver 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:

$$\log(R_{t,i}) = \log(S_{t,i}) + a_i - b_i S_t - M_{t,i} - \alpha_t + e_{t,i} \qquad [8]$$

Where:

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

In the version of the alpha model used to date, the series of additional mortalities is described by a linear relationship with further explanatory variables. The retrospective alpha series is modeled in the BSM is as follows:

$$\alpha_t = b_1'(1/F_t) + b_2'(E_t/F_t) + b_3' Step_t - \log(D_t P_t + 1 - P_t) + b_0' \qquad [9]$$

Where

b_j'	=	Regression coefficients. The coefficient 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 Hydro-related extra mortality Hypothesis (Alpha Model)

The prospective formulation of the hydro-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). Specifically, the assumed prospective relationship is

$$(1- l_{n,t,y})/(1-V_{n,t,y}) = (1-\overline{l}_{n,r})/(1-\overline{V}_{n,r}) \;, \qquad [10]$$

Where the bars represent averages of brood years 1975-1990. For convenience, the subscript r denotes a retrospective value and the subscript y, a prospective value. As before, V_n represents the in-river survival estimate supplied by the passage model, and l_n represents the post-Bonneville survival factor for in-river fish. In the latest round of analyses, the retrospective estimate of l_n is

$$l_n \quad = \quad \exp(-Step_t). \qquad [11]$$

In other words, prior to 1975, l_n is assumed be be equal to one, and afterwards, its estimate is equal to exp(-STEP), where STEP is the 1975-1990 level of the factor variable $Step_t$.

This, we believe, was not an appropriate formulation of the hydro-related extra mortality hypothesis because the step function above ignores the year-to-year variation in extra mortality. The step function was useful for estimating the effects of a regime shift, in which the mean productivities are assumed to shift downward in brood year 1975. However, the hydro-related extra mortality hypothesis really states that as in-river survival fluctuates up and down (on a *yearly* basis), so does the extra mortality. Thus we developed model that allowed for yearly fluctuation of extra mortality, namely:

$$a_t = b_1'(1/F_t) + b_2'(E_t/F_t) - b_3'\log(V_{n,t}) - \log(D_tP_t + 1 - P_t) + b_0' \quad , \qquad [9']$$

We use [9]' instead of [9] above to test the hydro-related extra mortality hypothesis.

This formulation makes it easy to test the hydro-related extra mortality hypothesis retrospectively and allows for year-to-year variation in extra mortality with respect to in-river mortality. These are requirements for applying weight of evidence to this hypothesis. We use a one-sided t-test to test the hypothesis that $b_3' = 0$ against the alternative that $b_3' > 0$ using the 1952-1990 data and the 1975-1990 data as before. When we test the 1975-1990 slope, we allow a different slope for the two periods 1952-1974 and 1975-1990. In that case b_3' is the slope corresponding to -log(V_n) for 1975-1990. In order to conduct a single test for each passage model and set of years, we used the average values of $V_{n,t}$, D_t, and P_t reported for each year and passage model.[1]

Results

Delta Model Results

There is no significant positive relationship (at the 0.05 level) between *Vn* and l_n using either the CRiSP or FLUSH passage models (Table 1.0). This is true for both the recent part of the record (i.e., brood years 1975-1990) and the entire record (1952-1990). These statistical results confirm what we suspected based on the plots of l_n versus V_n: there is no statistically positive relationship between them (See Figures 2-5).

[1] CRiSP has three different retrospective passage analyses, and FLUSH has eight, depending on assumptions regarding bypass survival and other factors. We average the values for each passage model before estimating the retrospective equations. This results in one average value for CRiSP and one for FLUSH.

Table 1.0 Hypothesis tests using the Delta Model. (n.s. = not significant at 0.05 level).

Brood Years	Passage Model	d.f.	t-value	p-value
52-90	CRiSP	37	0.3348719	0.37 (n.s.)
75-90	CRiSP	14	0.001964402	0.50 (n.s.)
52-90	FLUSH	37	-1.656603	0.95 (n.s.)
75-90	FLUSH	14	0.4387264	0.33 (n.s.)

Alpha Model Results

There was no significant positive relationship between extra mortality of in-river fish and in-river mortality for the Alpha Model. In fact, in each case the coefficient corresponding to -log(V_n) is negative, indicating a negative relationship between extra mortality and direct mortality. Thus we find no support for the hydro-related extra mortality hypothesis using the ALPHA model.

Table 2.0 Hypothesis tests using the Alpha Model (n.s. = not significant at the 0.05 level).

Brood Years	Passage Model	b_3' estimate	d.f.	t-value	p-value
52-90	CRiSP	-6.217e-001	228	-4.7407695	1.000 (n.s.)
52-90	FLUSH	-4.586e-001	228	-2.0781051	0.981 (n.s.)
75-90	CRiSP	-3.557e-001	227	-2.3708325	0.873 (n.s.)
75-90	FLUSH	-7.939e-002	227	-0.3466440	0.606 (n.s.)

Discussion

The tests of the hydro-related extra mortality hypothesis using the retrospective data show no statistically significant positive relationships between the direct and extra in river mortalities regardless of the passage or life-cycle model employed. Fortunately, the retrospective data includes a wide range of direct in-river survival estimates for both the CRiSP and FLUSH models over brood years 1952-1990. During this time period, average CRiSP direct in-river survivals range over 0.04-0.74, while average FLUSH survivals range over 0.01-0.87. Furthermore, the regressions for the 1952-1990 do not suffer from the defect of having too few data points at the higher or lower end of the covariate's range (Figures 2-5). In this case, we cannot claim that a poor design or data sample is driving the regression results. One defect that exists with the regression model of the 1952-1990 data (using the Delta life-cycle model) is a larger variance of residuals at lower in-river survivals (Figures 2 and 4). However, the 1975-1990 data do not suffer from this defect and confirm the results of the longer time series (Figures 3 and 5).

We believe that the hydro hypotheses should be reformulated to reflect the true correspondence between Vn and ln, instead of using the un-falsifiable relationships that are now employed. The current formulations are either untestable (in the case of the Delta life-cycle model) or inappropriate (in the case of using the step function in the Alpha life-cycle model.) The relationship employed between these survivals in the future should be no stronger than the relationship seen in the past. This should be a guiding principle for our prospective Bayesian simulation modeling.

The regression models described here can be run prospectively by sampling from the posterior distributions of the regression parameters and the variances of the error terms and by using prospective values of the explanatory variables (Gelman *et al.* 1997). The machinery to generate prospective values of a dependent model variable using retrospective parameters is already in place in the Bayesian Simulation Model.

References:

Deriso, R., D. Marmorek, and I. Parnell. 1996. Retrospective analysis of passage mortality of spring chinook of the Columbia River. Chapter 5 of PATH report "Plan for Analyzing and Testing Hypotheses: Draft Final Report on Retrospective Analyses," July 29, 1996.

Gelman, A., J.B. Carlin, H.S. Stern, and D.B. Rubin. 1997. Bayesian Data Analysis. Chapman & Hall, New York.

Marmorek D.R. and C. Peters (Editors). 1998. Preliminary Decision Analysis Report on Snake River Spring/Summer Chinook. February 4, 1988. ESSA Technologies Ltd., 3rd Floor, 1765 West 8th Avenue, Vancouver BC, V6J 5C6. Canada.

Mundy, P.R. and 9 co-authors. 1994. Transportation of juvenile salmonids from hydroelectric projects in the Columbia River Basin; an independent peer review. Final report, U.S. Fish and Wildlife Service, 911 N.E. 11th Avenue, Portland, Oregon 97232-4181.

Raymond. H.R. 1988. Effects of hydroelectric impoundments on migrations of juvenile chinook salmon and steelhead in the Columbia River Basin. North American Journal of Fisheries Management 8:1-24.

Williams. J.G. 1989. Spring River spring and summer chinook salmon: Can they be saved? Regulated Rivers: Research and Management: 4:17-26.

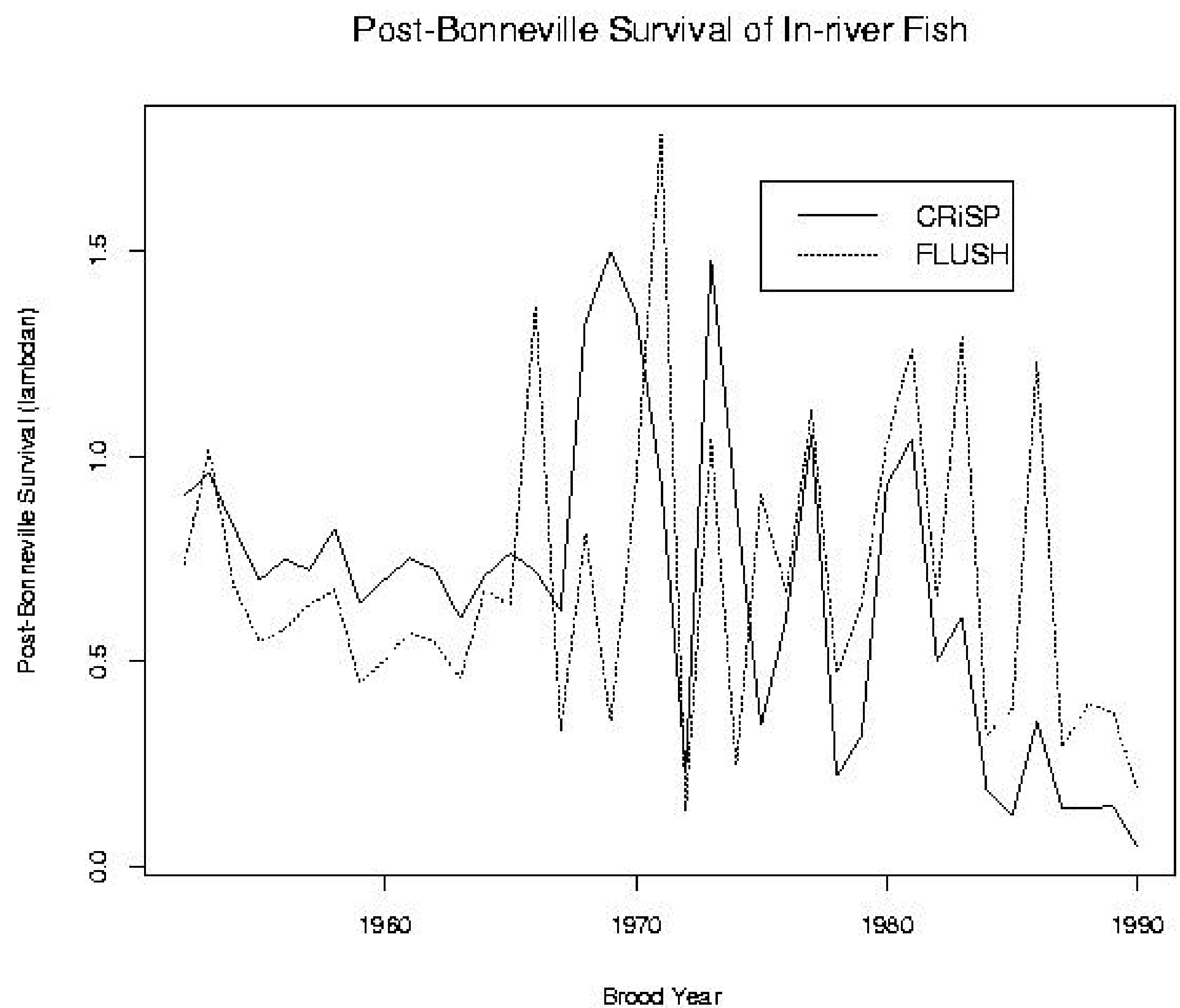

FIGURE 1. Post-Bonneville survival factors of in-river fish (Delta Model)

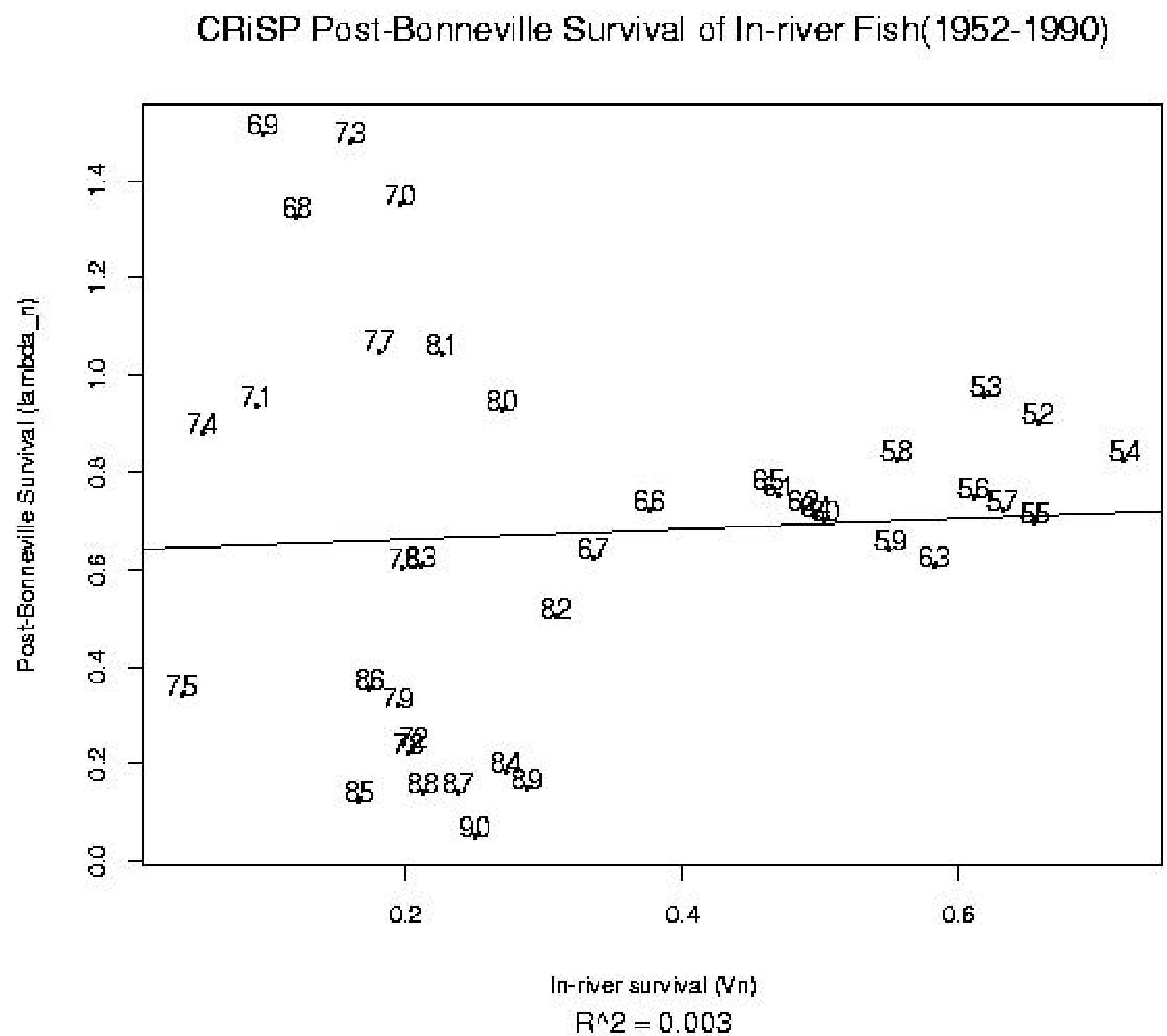

FIGURE 2. The relationship between lambdan and Vn using CRiSP and the Delta model (52-90)

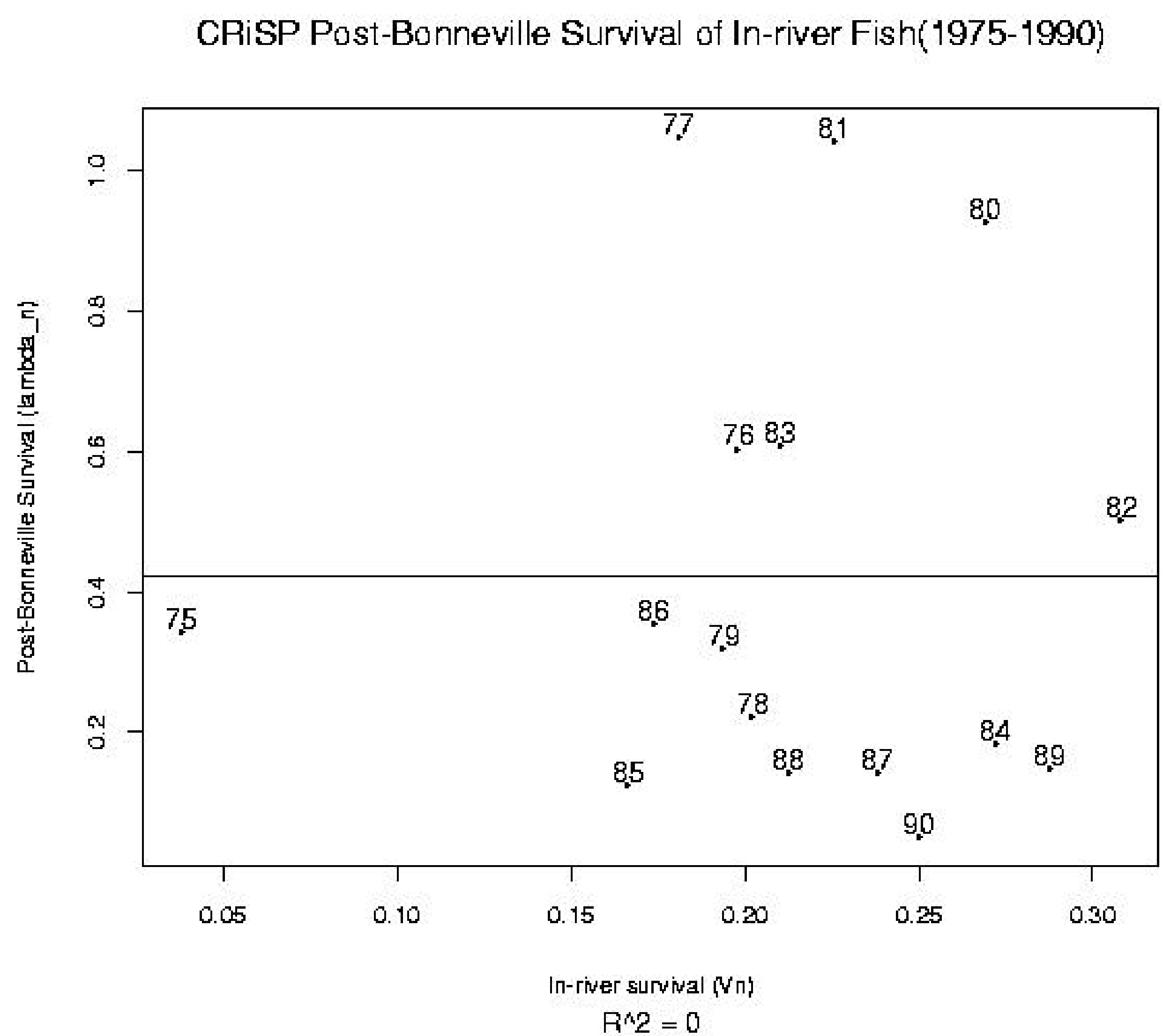

FIGURE 3. The relationship between lambdan and Vn using CRiSP and the Delta Model (75-90)

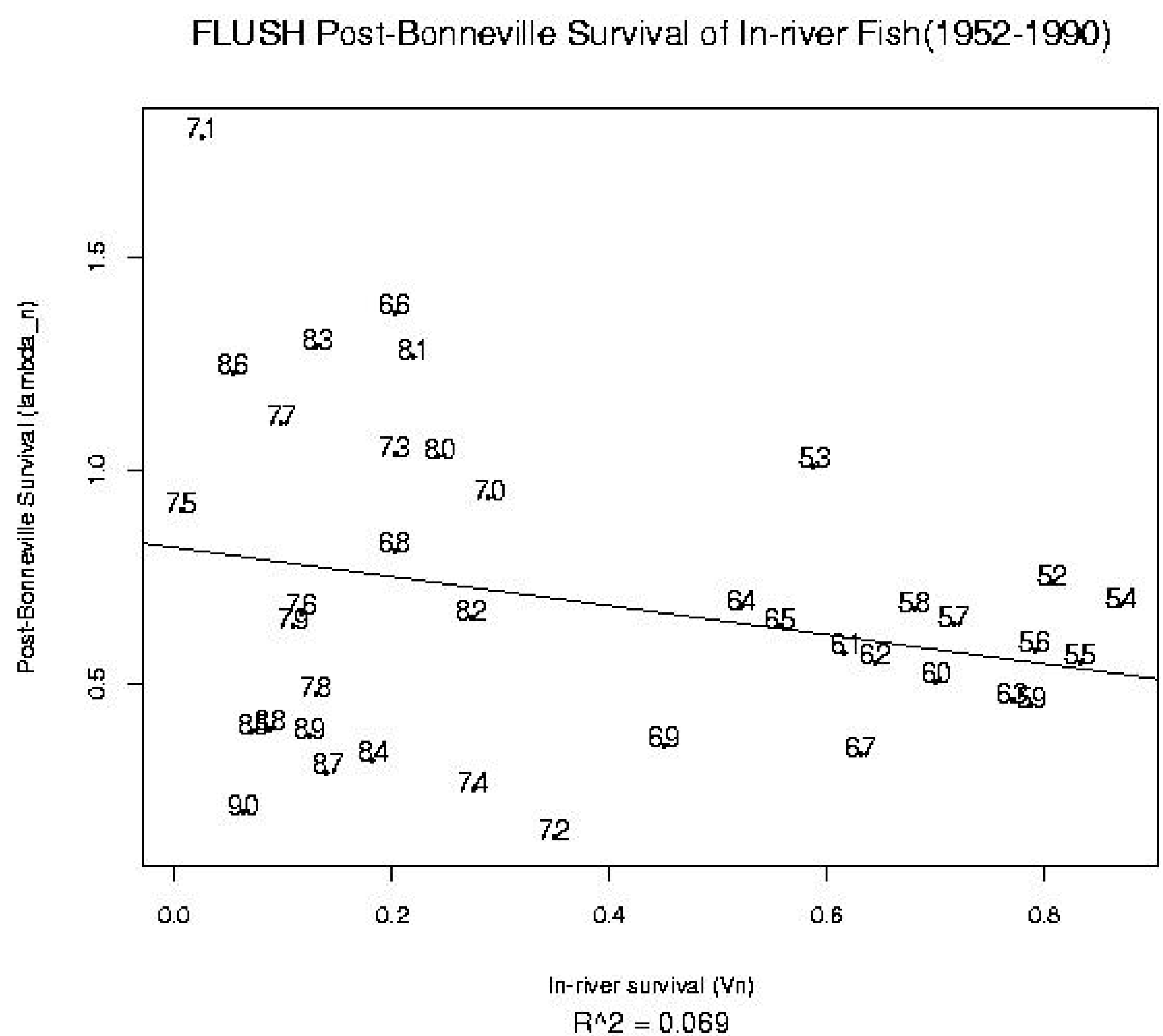

FIGURE 4. The relationship between lambdan and Vn using FLUSH and the Delta model (52-90)

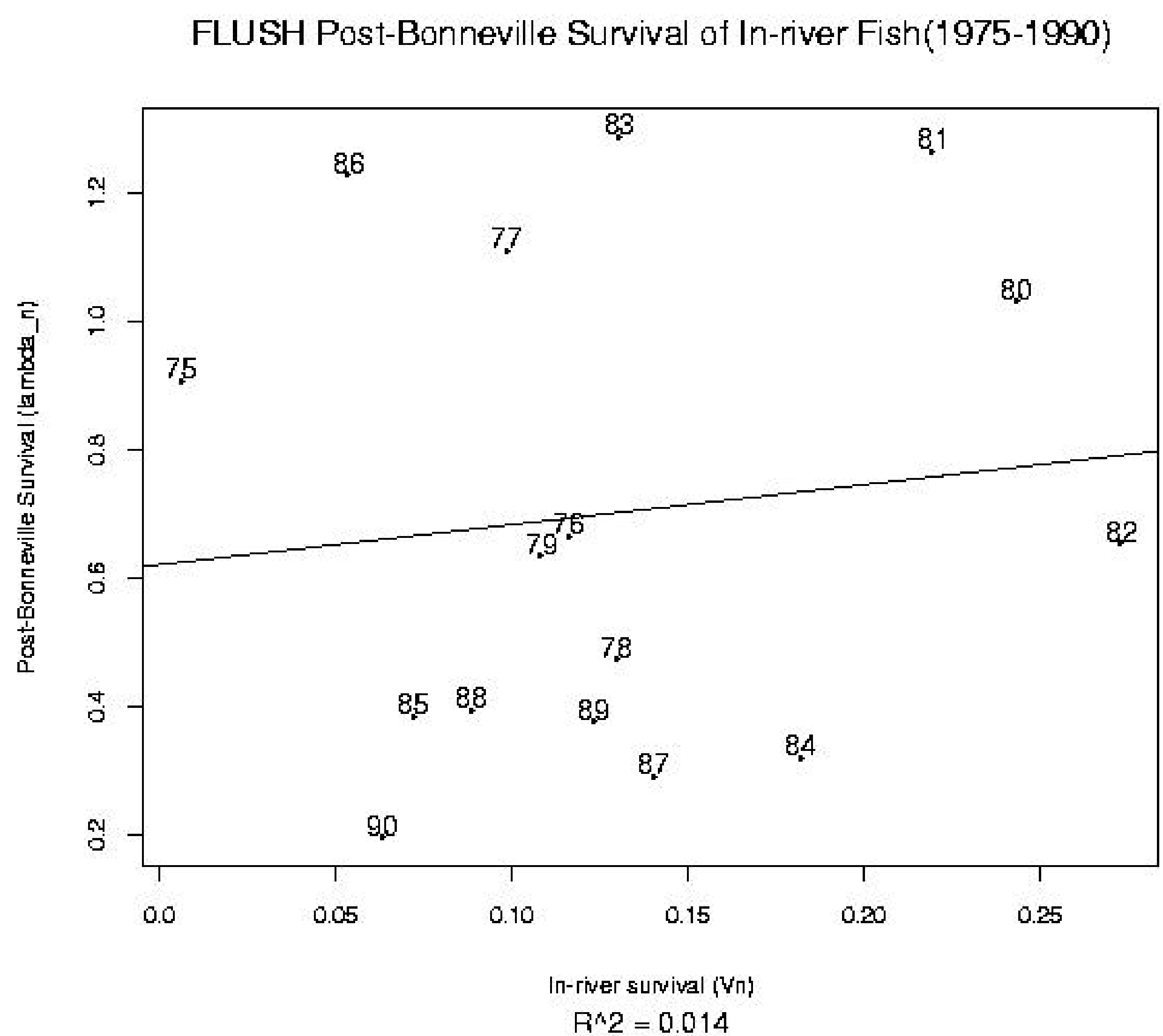

FIGURE 5. The relationship between lambdan and Vn using FLUSH and the Delta model (75-90)