ENVIRONMENTAL VARIATION AND POPULATION CHANGE: FORECASTING SPRING CHINOOK RUNS IN TWO OREGON COASTAL RIVERS

Daniel B. Botkin[1], Matthew J. Sobel[2], Lloyd G. Simpson[3], Kenneth Cummins[4], and Lee M. Talbot[5]

[1] University of California, Santa Barbara, and Center for the Study of the Environment, Santa Barbara, CA 93160.

[2] Case Western Reserve University, Cleveland, OH, 44106.

[3] NCR Modeling and Analysis Practice, Santa Paula, CA, 93060.

[4] Humboldt State University, Humboldt, California.

[5] George Mason University, Fairfax, VA 22030.

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Abstract. In this paper, we analyze correlations between adult spring chinook salmon (*Oncorhynchus tshawytscha* Walbaum) returns and river flow, hatchery releases and ocean troll catches in the Rogue and Umpqua Rivers and their tributaries in southern Oregon. Adult returns and water flow vary widely from year to year. Results suggest that variation in stream flow and number of smolts released by a hatchery can be used to forecast numbers of returning adults three and four years in the future. In contrast, present methods restrict forecast to a few months prior to a season. Water flow correlates positively with adult returns in 173 of the 174 cases. Hatchery releases are *negatively* correlated in 17 out of 17 four years before and 16 of 17 releases three years before. This suggests that hatchery releases may be ineffectual or actually diminish wild escapements. The statistical procedure known as jackknife models is used because the data set is small (1975 to 1992). With this method, 174 jackknifed models have good statistical properties, including R^2 values from 0.60 to 0.98 and from 0.50 to 0.96 for the three- and four-year models, respectively. The analysis suggests that environmental variation is useful as part of forecasting methods, providing much longer lead times than available with current methods.

1. INTRODUCTION

One of the most challenging problems for salmon conservation and management is the development of accurate methods to forecast the number of returning adults and thereby determine appropriate harvest levels. In this paper we show that environmental variation can be a useful forecasting tool. The overall purpose is to present the potentials of a general approach, rather than claim that a specific model or set of parameters is universally correct.

Specifically, we investigated water flow and hatchery releases as predictive variables for the number of returning adult spring chinook salmon in Oregon Coastal Rivers. The approach uses statistical regression models that do not establish formal causal mechanisms, but we discuss plausible causal roles of river flow and hatchery releases that might account for the results.

Advantages of this method are: (1) three and four year forecast in advance of a harvest season, in contrast to present methods that provide less than a year and as little as three months forecasts in advance of the fishing season; (2) river specific forecasts, in contrast to standard methods in use, which provide forecasts based on regional data and are not river specific. We also explore correlations between ocean troll catch and escapement to fresh water because troll catch is used in some present methods for setting in-river catch.

Others have examined the relationship between water flow early in the life cycle of a cohort and the return of adult chinook (Kjelson et al. 1981,1991; Speed and Ligon 1994), but the work reported here is, to our knowledge, the first attempt to develop formal forecasting tools for coastal rivers based on water flow and hatchery releases.

The remainder of the paper is organized as follows. Section 2 presents some fundamental information on the life cycle of spring chinook; section 3 discusses limitations of the data; and section 4 explains our statistical methods. The emphases are on preliminary analyses (section 4.1), time lags (section 4.2), regression variables (section 4.3), and autocorrelation (section 4.4).

Section 5 presents results for the Rogue River and the North Fork of the Umpqua River, beginning with presentation of the basic data and their implications. Forecast models are presented in section 5.1, which begins with an explanation of our statistical jackknife analyses (section 5.1.1). Results of the jackknife analyses (section 5.2.) are followed by the forecast equations (section 5.2.1).

Section 6, Discussion, considers the explanatory power of environmental variation;whether hatcheries are effective (section 7.1); comparison of the forecast equations with present methods (section 7.2); and the need for further research (section 7.3). Conclusions and acknowledgements are presented in sections 7 and 8, respectively.

2. SPRING CHINOOK LIFE CYCLE

Salmon have a life cycle among the most complex of all vertebrates, exposing them to a variety of habitats not experienced by most species. The life cycle of chinook salmon begins with eggs hatching in a stream. After spending months to a year or more in streams, survivors mature to smolts and migrate to the ocean where they grow into adults. After a period of two to six years in the ocean, adult fish return to fresh waters to spawn. In general, about 70% of the returning adults are 3 or 4 years old. The number of adult salmon returning to a river is referred to as the "escapement," a term we will use throughout. A complete explanation of run size might involve factors such as: ocean temperature and upwelling; riparian vegetation cover; status of gravel in stream beds; availability of habitats resulting from the presence of large woody debris and gravel beds; abundance of predators in the ocean and along rivers and streams; regulated and unregulated human catch, as well as water flow.

At the latitudes of the Rogue and Umpqua basins, spawning generally begins in November (Groot and Margolis 1991). However, spawning of spring chinook in the Rogue above Gold Ray Dam occurs between the first week in September and the end of October, peaking in the first week of October (Satterthwaite et al. 1992).

Although chinook adults return to spawn after varying lengths of time in the ocean, the majority spawn at ages three (20 percent of the cohort) and four (49 percent of the cohort) with males typically spawning at an earlier age than females (Groot and Margolis 1991, Satterthwaite 1991).

3. THE DATA AND THEIR LIMITATIONS

Scientists have long studied sizes of spawning runs, yet knowledge remains incomplete. On the Rogue and Umpqua Rivers, adult salmon are counted as they pass a fish ladder traversing a dam located downstream from a major hatchery (Gold Ray Dam on the Rogue and Winchester Dam on the North Fork of the Umpqua). Sections of the watersheds of these rivers have different logging practices, agricultural uses, urbanization, and other land uses that could confound correlations between water flow and adult returns.

On the Rogue River adequate counts of adults began in 1975 and hatcheries first released smolts in 1972. Thus 1975 is the first year in which hatchery smolts can be used as an explanatory variable for a three-year model and 1976 for a four-year model. Both hatcheries are upstream from the dams at which escapements are counted on their respective rivers. Therefore, at both dams the counts include hatchery fish and wild fish, but they do not include fish that spawn in tributaries below the dams.

U.S. Geological Survey gauging stations 14359000 at Gold Ray Dam and 14319500 at Winchester Dam (data from USGS) provided data on water flow volumes, reported in cubic feet per second. Reports of the Pacific Fisheries Management Council (PFMC, 1994b), provided data on escapements and troll catches in thousands of adult fish. It should be noted that most of the troll catch occurs offshore from the mouth of the Columbia River, not directly offshore from the mouths of the Rogue and Umpqua. Therefore, there is not necessarily a direct link between the fish caught by the troll catch and those that enter the two rivers. The PFMC regulates that catch closely. The Oregon Department of Fish and Game provided data on adult fish returns.

4. STATISTICAL METHODS

4.1 OVERVIEW

Our models consider the time period 1975 to 1992 and, speaking strictly, resulting regression models are valid only within the range of environmental conditions during that period. Relatively early in the study, the Oregon Department of Fish and Wildlife provided data on smolts released by the Rogue River hatchery, but could not find data from the Umpqua River hatchery. As the study was ending, the agency found Umpqua hatchery releases starting in 1978 but said that earlier years' data were permanently lost. This causes the gaps in the smolt release column in Table 1U.

First, we conducted preliminary data analyses exploring a range of possible relationships between numbers of returning spring chinook and water flow, hatchery releases and ocean troll catch. We focused on flow variables related to key times of year in relation to the chinook life cycle.

Using standard regression analysis, we examined these water variables three and four years prior to escapement: minimum one-day flow during the entire water year; total flow during the water year, and minimum one-day flow during November. The lowest one-day flow during November stood out in this exploratory analysis.

Next, we used jackknife analysis, explained in detail below, because of limitations of the data.

4.3 Regression Variables

The dependent variable in each regression model is the escapement of either total, wild (i.e., hatched in the stream) or hatchery (i.e., hatched in a hatchery) spring run chinook, measured at Gold Ray Dam on the Rogue River or Winchester Dam on the North Fork of the Umpqua River. Nine models were investigated for each river basin: three for each forecasting interval: four years, three years, and three months; and three measures of escapement: number of returning wild adults, hatchery-spawned adults, and the total adults.

Since there were at most eighteen data points for each river basin (1975-1992), it was particularly important to build models with as few explanatory variables as possible. The four-year and three-year regression models have three explanatory variables: a constant, November low flow, and the number of smolts released by the hatchery. The three-month model is the same except that the third explanatory variable is troll catch.

A water year runs from October to September. This could create ambiguity in data interpretation. To remove this ambiguity, we label the minimum one-day flow in November with the actual calendar year of the flow. For example, the 1990 datum for minimum one-day flow in November three years previously becomes the minimum flood during November 1987.

4.4 Autocorrelation

Hydrologic data are generally autocorrelated (Fiering, 1967). If escapement depends on water flow, then it too should show autocorrelation. Autocorrelation in the escapement data for the Rogue and Umpqua Rivers is indicated by the significance (at the 1 percent level) of the Durban-Watson statistic (Greene, 1990) in most of the estimated models. To evaluate the adequacy of each model structure, the complicating effect of autocorrelation was handled with the following standard transformation (Greene, 1990) of the data. Let n be the number of observations; let the escapement data be $y_1, \ldots, y_n$, and let ρ be the estimated autocorrelation coefficient of the model's residuals. Then replace each escapement datum y_t with $y_t - \rho y_{t-1}$, and proceed with the jackknife analysis discussed below.

5. RESULTS

Tables 1R and 1U contain the data: escapements of spring chinook adults, hatchery releases of smolts, water flow, and ocean troll catches. Escapement is counted at dams, and does not include fish that spawn in tributaries below the dam.

Table 1-R Rogue River Data

Fish data are in thousands; water flow is in cubic feet per second.

		Rogue	River	Data			
N	**Year**	**Total Adult Returns**	**Wild Adult Returns**	**Hatchery Adult Returns**	**Hatchery Releases 3 ys before**	**Ocean Troll Catch**	**Nov. Low Flow 3 yrs before**
1	1975	21.5	20.2	0.9	6	225	1630
2	1976	21.6	19.6	1.1	26.6	184	1500
3	1977	16.4	14.8	1.5	50.8	340	1540
4	1978	47.2	39.2	6.8	85.7	192	1900
5	1979	38.2	28.4	8.6	89.6	245	1360
6	1980	36.9	26.1	10.3	69.7	209	1370
7	1981	17.2	11.7	5.1	77.6	160.4	1280
8	1982	29.9	20.4	8.3	76.2	232.6	1330
9	1983	12.5	8.6	3.5	74.2	79.6	1200
10	1984	12.7	6.8	5.3	76.1	64.3	1240
11	1985	40.5	20.3	19.2	91.9	216.6	2110
12	1986	89.5	43.6	43.4	189.1	402.9	2310
13	1987	81.6	34.5	47.1	127.5	529.9	2070
14	1988	82.6	49.5	31.6	252.7	470	1596
15	1989	60.3	14.5	45.8	241.2	353.9	1790
16	1990	24.6	10.7	13.9	209.1	232.4	1010
17	1991	12.4	7.8	4.2	162.4	74.8	1210
18	1992	5.8	2.5	2.7	159.2	110.3	1340

Table 1-U Umpqua River Data

Fish data are in thousands; water flow is in cubic feet per second.

		Umpqua	River	Data			
N	Year	Total Adult Returns	Wild Adult Returns	Hatchery Adults Returns	Hatchery Releases 3 ys before	Ocean Troll Catch	Nov. LowFlow 3 yrs before
1	1975	10.6	5.4	5.2		225	1810
2	1976	10.7	5.5	5.2		184	1260
3	1977	12.2	6.8	5.5		340	2310
4	1978	8.2	5.4	2.8		192	1090
5	1979	9.5	5.5	4		245	2330
6	1980	7.6	5.7	1.9		209	1010
7	1981	8.7	4.6	4.1	178.1	160.4	1440
8	1982	8.4	6.5	2	152.1	232.6	735
9	1983	5.8	3	2.9	86.6	79.6	1160
10	1984	7	4.5	2.4	250.9	64.3	941
11	1985	13.5	7.5	6.1	206	216.6	999
12	1986	13.7	8.3	5.3	234.6	402.9	1600
13	1987	15.6	9.3	6.3	196.8	529.9	1570
14	1988	11.6	7.8	3.8	284.4	470	2230
15	1989	9.9	7.6	2.2	395.6	353.9	1380
16	1990	7.6	5.5	2	336.3	232.4	1630
17	1991	4.2	2.4	1.8	386.3	74.8	668
18	1992	5.2	2.5	2.5	442.4	110.3	728

The annual number of returning adults varies greatly over the time period, from 5,200 to 89,500 in the Rogue River and 5,200 to 15,600 in the Umpqua River. Variation appears to have patterns -- sets of years with high returns and sets with low returns (Table 1; Figure 1). Highest escapement occurs between 1985 and 1989, with another, smaller set of high values between 1978 and 1980. Wild and hatchery fish vary in similar patterns except for the earliest years, when hatchery releases were small. This suggests that the causes of variation apply to both hatchery and wild fish.

Variation in total escapement appears to match closely the pattern of November low water flow three years, except for a deviation for the last two years (Table 1; Figure 2).

Hatchery releases of smolts on the Rogue River generally increased during the observation period. Releases three years before match the general pattern of total adult returns until 1989, when the total escapement declines rapidly, while hatchery releases decline a much smaller percentage, from 250,000 to 150,000 (Figure 3). Total escapement closely tracks ocean troll catch three months before (Figure 4).

Figure 1: Total, Wild and Hatchery Returning Adults on the Rogue River

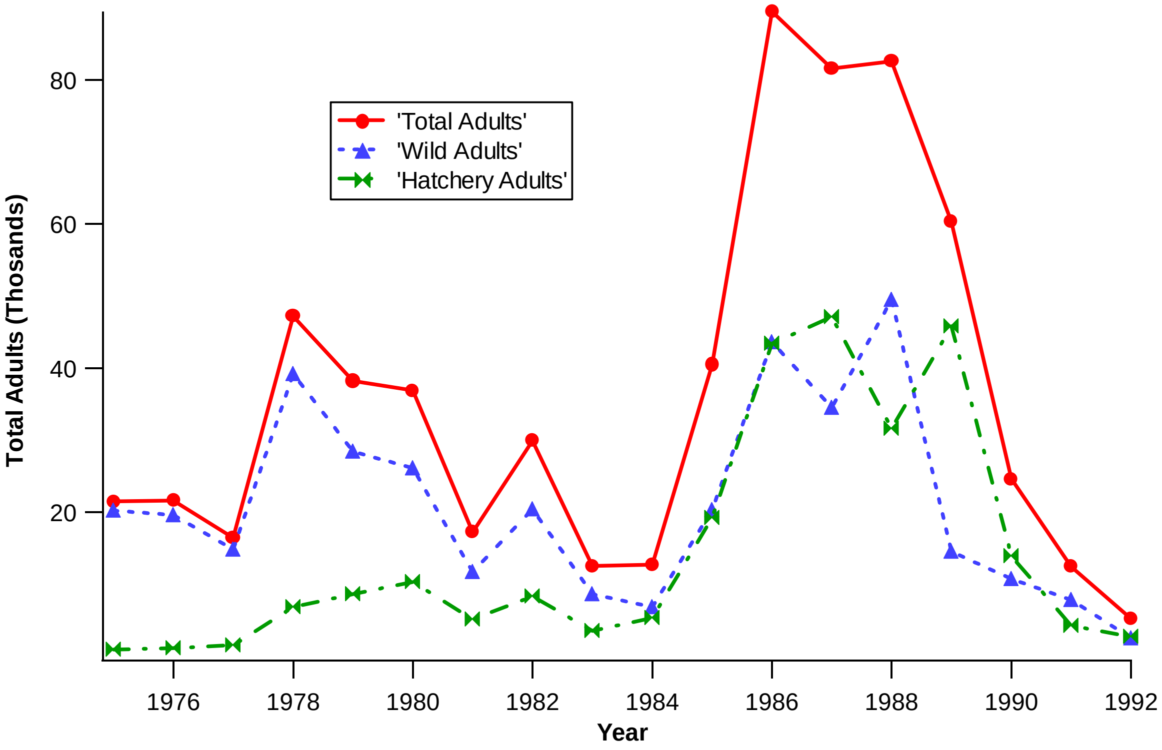


FIGURE 2 TOTAL ADULT RETURNS ON THE ROGUE RIVER VERSUS NOVEMBER LOW WATER FLOW 3 YEARS BEFORE

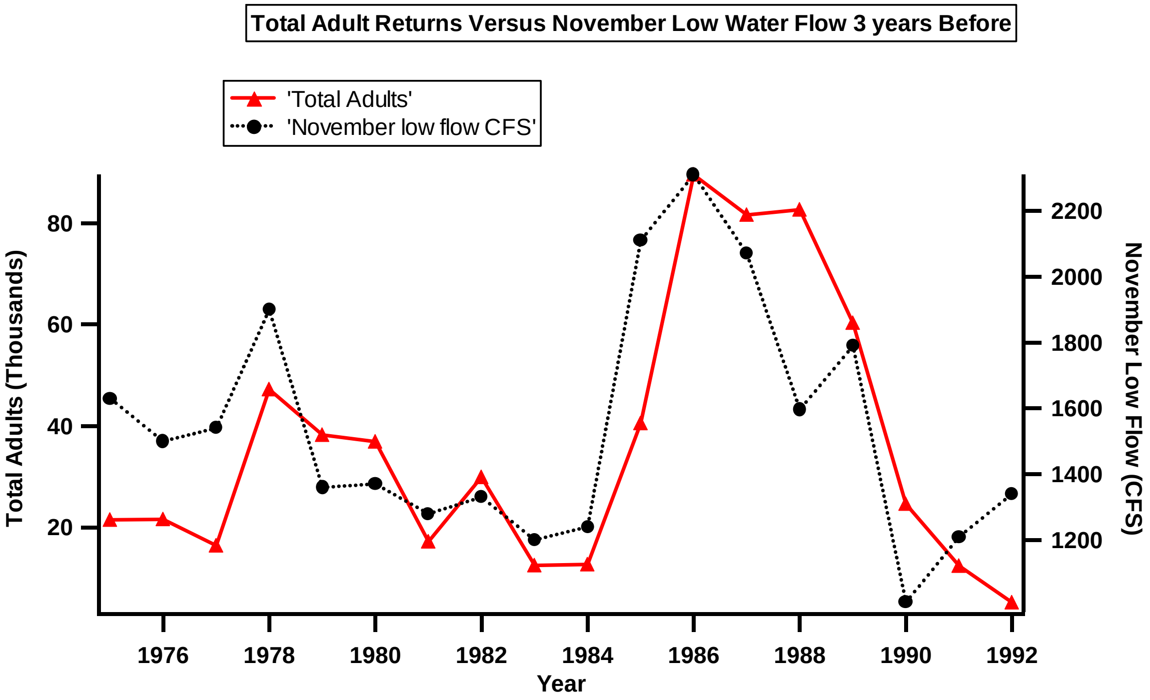


FIGURE 3:

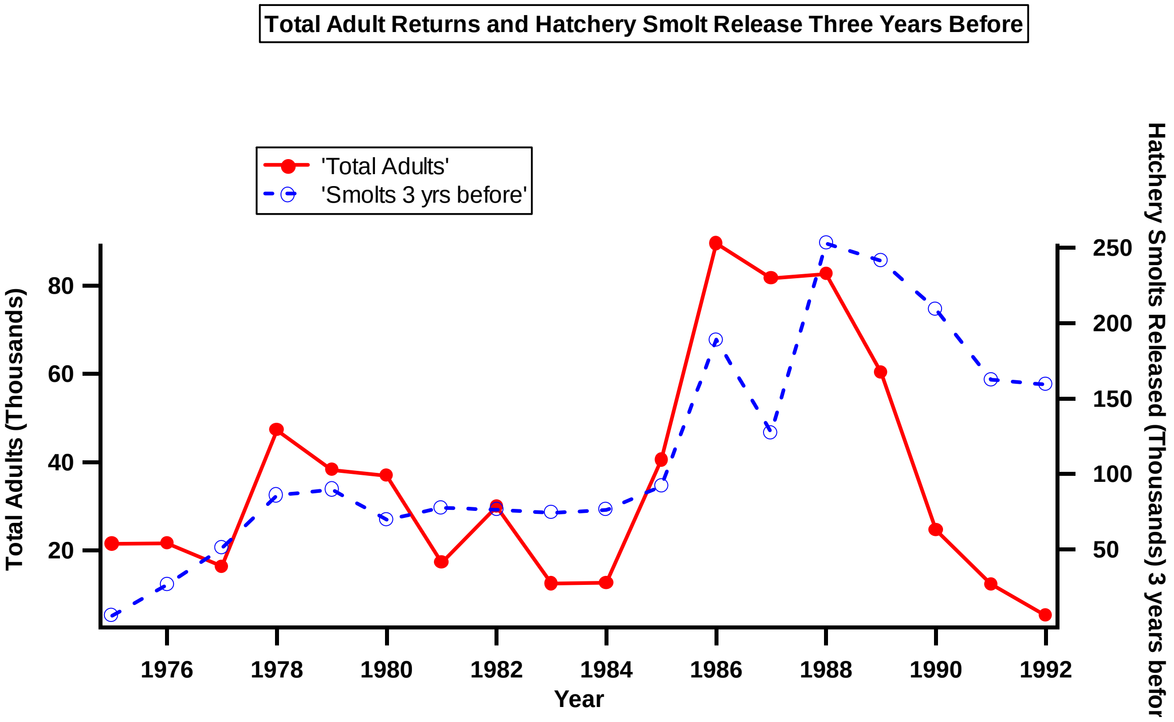
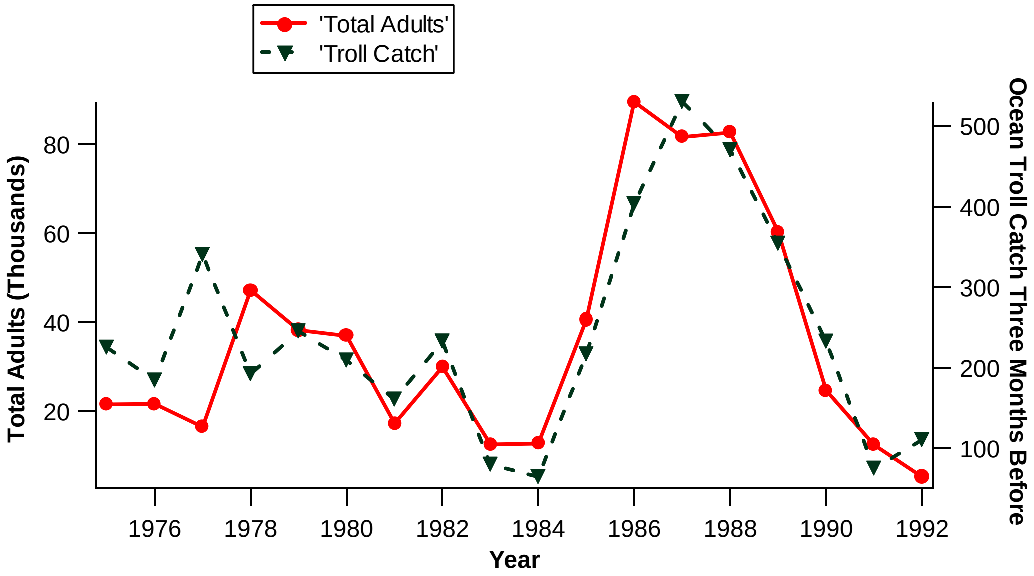

Total Adult Returns and Hatchery Smolt Release Three Years Before
'Total Adults'
'Smolts 3 yrs before'
Total Adults (Thousands)
80
60
40
20
Hatchery Smolts Released (Thousands) 3 years befor
250
200
150
100
50
1976
1978
1980
1982
1984
1986
1988
1990
1992
Year

FIGURE 4: TOTAL ADULT RETURNS VERSUS OCEAN TROLL CATCH 3 MONTHS EARLIER



5.1 FORECAST MODELS

The hatchery on the Rogue River first released smolts in 1972, which means that 1976 is the first year in which escapement data can be employed to estimate a four-year forecasting model with hatchery smolts as an explanatory variable. Since the study data terminated in 1992, there are eighteen data points for the three-month and three-year analyses, and seventeen data points for four-year analyses. The more limited Umpqua River hatchery data yield eleven data points for four-year analyses, twelve data points for three-year analyses, and eighteen data points for three-month analyses. This yields a total of 282 data points in eighteen combinations of forecast interval, river, and type of escapement (wild, hatchery, or total).

5.2.1 Jackknife Analyses

We employed a statistical jackknife procedure to guard against the excessive influence of individual data points or individual years. That procedure was used as follows. For each of the eighteen combinations of forecast interval, river, and type of escapement, we used all but one of the data points (that is, one year's data) and estimated a regression equation with three explanatory variables: constant, flow variable, and one other variable (hatchery smolt releases or ocean troll catch). Suppose that there are n cases in a combination of forecast interval, river, and type of escapement. Suppressing one of the n cases and estimating a regression equation yields estimates of the coefficient of the flow variable, the coefficient of the other variable, and a value for R^2. Repeating this suppression for each of the n cases generates n estimates of the coefficient of the flow variable, n estimates of the coefficient of the other variable, and n values for R^2.

If the forecast interval is four years, the “one other variable” is *Smolt4*, i.e. the number of smolts released from the hatchery four years before the escapement. If the forecast interval is three years, it is *Smolt3*, i.e. the number of smolts released three years previously. If the forecast interval is three months, then it is *Troll*, i.e the troll catch shortly before the escapement.

As an example, consider the four-year analysis of returning wild spawners on the Rogue River; here n=17, i.e. there are seventeen years of data. The explanatory variables are the one-day lowest flow in November (*NovMin4)* and the number of smolts released from the hatchery (*Smolt4)*, both four years prior to the escapement. Suppressing any year's data and estimating a regression with NovMin4 and Smolt4 (and a constant) as explanatory variables yields an estimated model based on sixteen years of data. So seventeen estimated models are obtained by suppressing each of the individual year's data. This yields seventeen cases, i.e. seventeen estimated coefficients for each of *NovMin4* and *Smolt4* and seventeen values of R^2.

Table 2. Summary of Jackknife Analysis

Fore-cast Interval	River	Depend. Variable	Flow Variable	Histogram Range	Other Variable	Histogram Range	R^2 Range	Std. Dev. Forecast Errors	Number of Cases
4 years	Rogue	Wild	NovMin4	.018 : .020	Smolt4	-.068 : -.047	.91 : .96	8.937	17
4 years	Umpqua	Wild	NovMin4	.007 : .015	Smolt4	.007 : .015	.80 : .88	2.6563	11
4 years	Rogue	Hatch	NovMin4	.006 : .010	Smolt4	-0.005 : .085	.50 : .69	12.789	17[a]
4 years	Umpqua	Hatch	NovMin4	-.0005 : .0008	Smolt4	.006 : .013	.55 : .67	2.3291	11[b]
4 years	Rogue	Total	NovMin4	.025 : .031	Smolt4	-.06 : 0.005	.78 : .88	17.177	17[c]
4 years	Umpqua	Total	NovMin4	.016 : .030	Smolt4	.0005 : .0030	.73 : .81	4.9109	11
3 years	Rogue	Wild	NovMin3	.013 : .016	Smolt3	-.04 : .04	.76 : .88	10.895	18[d]
3 years	Umpqua	Wild	NovMin3	.0011 : .0021	Smolt3	.011 : .015	.93 : .98	1.4272	12
3 years	Rogue	Hatch	NovMin3	.002 : .006	Smolt3	.074 : .087	.60 : .80	11.26	18
3 years	Umpqua	Hatch	NovMin3	.0008 : .0024	Smolt3	-.001 : .009	.74 : .90	1.646	12[e]
3 years	Rogue	Total	NovMin3	.016 : .024	Smolt3	.03 : .10	.72 : .85	22.878	18
3 years	Umpqua	Total	NovMin3	.0005 : .0037	Smolt3	.015 : .030	.86 : .96	2.7981	12
3 mos.	Rogue	Wild	NovMin3	.002 : .009	Troll	.02 : .07	.80 : .95	9.9858	18
3 mos.	Umpqua	Wild	NovMin3	0.00005 : .00095	Troll	.016 : .020	.87 : .94	1.2472	18
3 mos.	Rogue	Hatch	NovMin3	-.002 : .005	Troll	.03 : .08	.47 : .75	10.971	18[f]
3 mos.	Umpqua	Hatch	NovMin3	.0010 : .0018	Troll	.0035 : .0075	.73 : .84	1.5509	18
3 mos.	Rogue	Total	NovMin3	-.001 : .007	Troll	.11 : .17	.88 : .97	13.435	18[g]
3 mos.	Umpqua	Total	NovMin3	.0010 : .0018	Troll	.023 : .026	.83 : .90	2.6084	18

Footnotes for Table 2 (Summary of Jackknife Analyses)

[a] One of the 17 coefficients of *Smolt4* was negative.

[b] One of the 11 coefficients of *NovMin4* was negative.

[c] One of the 17 coefficients of *Smolt4* was positive.

[d] Three of the 18 coefficients of *Smolt3* were positive.

[e] One of the 12 coefficients of *Smolt3* was negative.

[f] One of the 18 coefficients of *NovMin3* was negative. One R^2 was below 0.5.

[g] One of the 18 coefficients of *NovMin3* was negative.

The first three columns of Table 2 specify the forecast interval, river, and type of escapement. The fourth column specifies the flow variable (either *NovMin4* or *NovMin3*, i.e. the lowest one-day flow during November three years prior to escapement).

Jackknife Analyses Results

Table 2 summarizes the 282 cases obtained by this process for each of the eighteen combinations of forecast interval, river, and type of escapement. The fifth column gives the range of values for the estimates of the coefficient of the flow variable. For example, the first row of Table 2 corresponds to the four-year analysis of returning wild spawners on the Rogue River. There are seventeen cases; the seventeen coefficients of *NovMin4* are confined to the interval 0.018 to 0.020. Note that *all seventeen coefficients of NovMin4 are positive*.

The sixth column gives the other explanatory variable, which is the number of smolts released from hatcheries four years before (*Smolt4),* the number of smolts released from hatcheries three years before (*Smolt3),* or the troll catch in the present year (*Troll catch).* For example, in the first row of Table 2, this variable is *Smolt4* because the forecast interval is four years.

The seventh column gives the range of values of estimates of the coefficient of the explanatory variable in column six. In the four-year analysis of returning wild spawners on the Rogue River, for example, the seventeen coefficients of *Smolt4* lie between –0.068 and –0.047.

The eighth column gives the range of values of R^2, the ninth column specifies the standard deviation of the forecast errors, and the tenth column states the number of cases.

The ninth column, the standard deviation, 8.937, was calculated as follows. When one of the 17 cases is suppressed, the remaining 16 cases yield regression coefficients which are then used to forecast the seventeenth (suppressed) dependent variable. The forecast error is the difference between the actual value of the suppressed dependent variable and the forecasted value. This yields seventeen forecast errors, from which a standard deviation can be calculated. In the first row of Table 1, 8.637 is the standard deviation of the seventeen forecast errors.

5.2.3 Forecast Equations

Forecast equations for the Rogue and Umpqua Rivers are presented in Tables 3R and 3U, respectively. Their structure mimics Table 2 and the coefficients are the medians in the jackknife analyses.

Table 3R Rogue River Forecast Equations Based on Jackknife Medians

Escapement & Forecast Interval	Equations
Wild – 4 years	$Y = 0.0188N - 0.05921F + 3.631$
Hatchery – 4 years	$Y = 0.00926N + 0.02363F - 1.125$
Total – 4 years	$Y = 0.02858N - 0.04281F + 6.973$
Wild – 3 years	$Y = 0.01481M - 0.01032H + 0.4207$
Hatchery – 3 years	$Y = 0.004008M + 0.08198H - 0.5677$
Total – 3 years	$Y = 0.01972M + 0.06913H + 5.328$
Wild – 3 months	$Y = 0.004178M + 0.06267T - 0.3297$
Hatchery – 3 months	$Y = 0.003111M + 0.05078T - 0.6676$
Total – 3 months	$Y = 0.001615M + 0.1466T + 2.302$

Note that the coefficients are the median values for the jackknife regressions.

The general form of the forecast equation is $Y = aT + bH + cF + dM + eN + f$

Where:

T = the ocean troll catch in the present year (taken 3 months earlier)
H = hatchery release, 3 years before
F = hatchery release, 4 years before
M = minimum 1-day flow during November, 3 years before
N = minimum 1-day flow during November, 4 years before
a, b, c, d, and e are coefficients of the explanatory variables
f is a constant in the equation

Table 3U Umpqua River Forecast Equations Based on Jackknife Medians

Escapement & Forecast Interval	Equations
Wild – 4 years	$Y = 0.00198N - 0.01007F - 0.3885$
Hatchery – 4 years	$Y = 0.0004582N + 0.008218F - 0.2011$
Total – 4 years	$Y = 0.002231N + 0.01907F + 0.762$
Wild – 3 years	$Y = 0.001638M + 0.01413H - 0.5483$
Hatchery – 3 years	$Y = 0.001284M + 0.005653H - 0.2619$
Total – 3 years	$Y = 0.00289M + 0.01989H - 0.5327$
Wild – 3 months	$Y = 0.0003988M + 0.01842T + 0.1375$
Hatchery – 3 months	$Y = 0.001404M + 0.005454T + 0.05024$
Total – 3 months	$Y = 0.001522M + 0.02467T + 0.1453$

Note that the coefficients are the median values for the jackknife regressions.

The general form of the forecast equation is $Y = aT + bH + cF + dM + eN + f$

-where:T = the ocean troll catch in the present year (taken 3 months earlier)
H = hatchery release, 3 years before
F = hatchery release, 4 years before
M = minimum 1-day flow during November, 3 years before
N = minimum 1-day flow during November, 4 years before
a, b, c, d, and e are coefficients of the explanatory variables
f is a constant in the equation

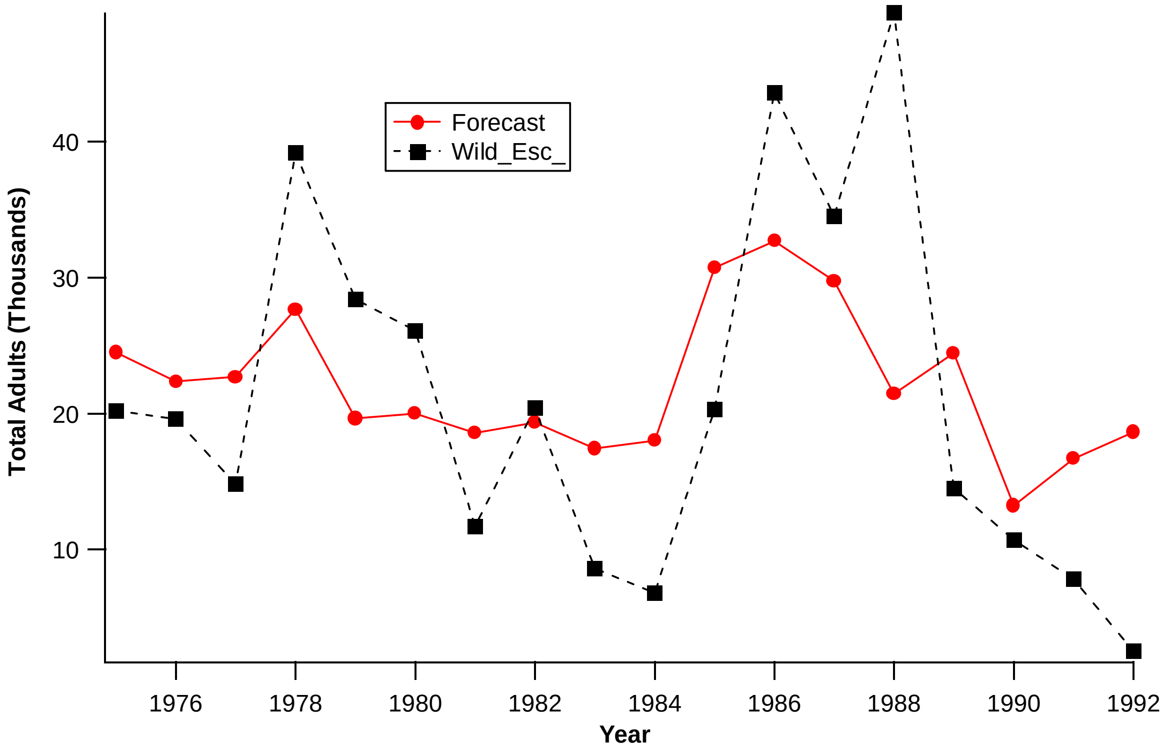
For example, the first row of Table 3R gives the following four-year forecast equation for wild escapement on the Rogue River:

$$\mathit{Wild\ Escapement} = 0.0188\ \mathit{NovMin4} - 0.05921\ \mathit{Smolt4} + 3.631$$

From the first row of Table 2, the standard deviation of the 17 forecast errors was 8.937. The 17 coefficients of *NovMin4* ranged from 0.018 to 0.020 with a median of 0.0188. The 17 coefficients of *Smolt4* ranged from –0.068 to –0.047 with a median of -0.05921. The 17 constants had a median of 3.631.

Results of some of the Rogue River prediction equations are illustrated in Figure 5, a graph of observed and forecasted wild escapement three years ahead calculated with the fourth equation in Table 3R. This equation forecasts wild escapement using a constant and hatchery releases and November 1-day minimum flow - three years before. The predicted values of total escapement have the same pattern as the counted escapement. When the measured returns are high, so are the predicted returns; when the measured return are low, so are the predicted values.

Figure 5: Three-year Forecasted and Actual Wild Adult Returns on the Rogue River



6. DISCUSSION

Adult returns on the Rogue and Umpqua Rivers between 1972 and 1992 are characterized by variation rather than constancy. Patterns of v*ariations in escapement generally follow patterns of variation of the three independent variables*---November low water flow, hatchery releases, and troll catch.. The high R^2 values in Table 2 suggest that interannual variations of water flow, hatchery releases and troll catch account for a high proportion of interannual variations in escapement of spring chinook. We would expect the inclusion of the missing Umpqua smolt release data to improve the reliability of the Umpqua forecast equations.

Water flow has positive coefficients in all 90 cases for three-year forecasts. *We conclude that there is strong evidence that higher flows favorably affect escapements*.

Since the dams on the Rogue and Umpqua Rivers regulate water flow, all flows below these dams prior to the end of the spawning period in November have been thought by some to be within levels that avoid the hindrance of adult spawners moving upstream, even in the upper river. *The results presented here suggest, to the contrary, that whatever flow regulation takes place is insufficient to avoid the effects of low flow on spring chinook.*

There are several reasons why spring chinook life cycle may be dependent on fall river flow. Heavy precipitation in the winter and low precipitation in the summer in western Oregon result in relatively low average flows during summer and early fall. November marks the beginning of the rainy season and is typically the first month of increased flow. November flows are therefore likely indicators of fall flows that are critical to egg incubation, juvenile rearing, and spawning success of spring chinook.

Most spring chinook enter estuaries and lower reaches of larger rivers during the high spring flow, although some enter during low flows in late spring and early summer. Most fish cross Gold Ray Dam before low summer flows. Over the summer and early fall, they migrate to the spawning grounds, waiting for sufficient flows to reach these grounds.

In a drought year, upper springs may be impassible for salmon until fall rains begin. If November rains are low or delayed, adults may not be able to reach spawning grounds at all, or in time for successful spawning. This is especially true for spring chinook, steelhead and cutthroat trout. They tend to spawn higher up the river networks than summer chinook or chum salmon, which spawn in tributaries near the ocean, and may be less sensitive to November flow (Groot and Margolis 1991).

Eggs incubate from September through February with emergence from the gravel occurring from December through February. Autumn flows are also important to benthic invertebrates that serve as food for the rearing juveniles.The data encourage an exploration of the dependence of escapement on environmental variation, i.e. November low water flows.

Adequate water flow facilitates upstream passage of spawners and downstream passage of smolts. Adult spring chinook typically enter estuaries and rivers in late spring and early summer. On the Rogue River, they pass Gold Ray Dam, where they are counted, between mid April and mid August, with the peak of migration occurring in early June (Satterthwaite et al. 1992).

Adequate fresh water flow is crucial for maintaining sufficient water depth and an appropriate temperature range in the system of pools and riffles that constitute spawning and rearing habitats. Abundant or adequate river water flow maintains lower stream temperatures during warm weather. Some evidence suggests that water temperature may be an especially important habitat characteristic to salmon in southwestern Oregon and northern California rivers.

On the other hand, too much water flow may have a negative effect on spawning and rearing. For example, if stream flow is too great, then gravel beds with eggs may be scoured away and juvenile fish may be washed downstream prematurely.

If water flow is important to successful hatching of eggs, rearing of young fish, migration of those fish downstream, or return upstream of adult fish to spawn, then one would expect a strong correlation between adult spring chinook escapement and fresh water flow three and four years beforehand.

In contrast to water flow, hatchery releases three and four years previous appear to correlate *negatively* with escapement. For the three-year forecast interval, hatchery smolt releases (variable *Smolt3* in Table 2), have 15 negative coefficients and three positive coefficients for wild escapement on the Rogue River. A*ll seventeen coefficients of Smolt4 are negative* -- the greater the number of smolts released from hatcheries, the lower the number of returning adults.. *These results suggests that hatchery releases may be ineffectual or actually diminish wild escapements.*. The paucity of Umpqua hatchery release data obstructs an assessment of the effect of hatchery releases on that river.

At least for the period 1975 to 1992, increases in November low flow appear to have been more instrumental than hatchery releases in determining future return of adult fish. This is not a statement about cost effectiveness, because we do not have data to compare the costs of establishing and operating hatcheries with the costs of adjusting flow where that is possible, as with the dams on the Rogue and Umpqua Rivers and their tributaries.

There may be a nonlinear relationship between hatchery releases and future adult returns. Hatcheries might be beneficial when hatchery releases are relatively small, but the habitats might become saturated by hatchery releases at comparatively low abundances. If this were the case, then the initial results from a hatchery would be encouraging, but an increase in hatchery smolt release might decrease the benefits of those releases. This could occur if a particular habitat were an environmental bottleneck, and if its capacity were exceeded by wild fish in combination with a comparatively small number of hatchery releases. Without continual monitoring of the relationship between hatchery releases and escapement as we suggest later in this paper, an operator of a hatchery might be encouraged by initial results to continue to expand the production of fish beyond a useful level. Monitoring and recalculation of the forecast equations in this paper could help avoid overallocation of resources to hatchery production.

We emphasize that, strictly speaking, results are valid only within the range of environmental conditions during that period. Some environmental factors change more slowly than that time period, such as some forms of land use, land cover, and climate. These might affect salmon abundance over the long run but may not have changed significantly during the period of observation. As a result, specific regression equations might not be valid under altered global meteorological conditions such as might occur from global warming, changes in flow regulation, a natural shift in predominant weather patterns, or greatly accelerated changes in land use. This is one of the reasons that we do not claim that the specific equations reported here have general applicability; only that the approach may be useful generally.

6.2 Comparison with Present Methods

Present methods used in Oregon are not river specific (PFMC, 1994a). Instead, "Oregon coastal chinook are managed for an aggregate spawning escapement of 150,000 to 200,000 naturally spawning adults" (PFMC, 1994b). Present forecasts are based on a count of the number of jacks (2 year old fish that return prematurely, do not spawn, and sometimes return to the ocean). This method uses a regression equation in which the explanatory variable is the number of jacks returning in one year and the dependent variable is the escapement of adults (age 3) the following year. This method assumes that the number of jack fish is a constant fraction of the total population, and therefore, provides a leading indicator of adult returns the next year. However, on the Rogue and Umpqua Rivers, spring chinook jacks are defined as fish less than 24 inches in length, which actually includes both two- and three-year old fish (PFMC, 1994a). This means that jack numbers (the actual number of age 2 fish) are not actually measured and, therefore, should not be used to forecast the next year age 3 ocean adults, because the ages are mixed in the data.

A further problem with present methods is that escapement estimates for the Oregon coastal aggregate population are based on a combination of three kinds of information: observations of jacks entering the Salmon River; observations of jacks entering the Klamath River (in California); and a projection based on a model for the Salmon River (a tributary of the Columbia River). These forecasts reflect the untested assumption that the behavior of jacks on the Klamath and Salmon Rivers reflects their behavior on the coastal rivers in western Oregon including the Rogue and Umpqua Rivers. An additional problem is that forecasts based on ocean troll catch and jack returns allows only a few months for fishermen to adjust to revised catch limits.

In some cases, within-river catch limits are based on the ocean troll catch, using information obtained three months before the start of a within-river fishing season. Even though there is an apparently close correlation between troll catch and adult escapement (see Table 2 and Figure 4), the use of troll catch combined with jack fish would appear to constitute a questionable basis for scientific management of salmon in specific rivers, for the following reasons. Troll catch is determined by preset catch limits; troll catch occurs at some distance for any specific coastal river; the method makes use of data on jack fish that are questionable as leading indicators, as explained earlier; also are not specific to a river; and in any event, the actual in-river catch limits are the results of negotiations among government agencies.

In figure 5, the primary difference between predicted and observed escapement is that observed values have greater variation. This is to be expected because the forecast refers to an expected value, about which there is additional random variation. By definition, the actual value of a random variable consists of an expected value plus a random variation from the expected value. We estimate the expected value, but we cannot estimate the random variation that is superimposed on the expected value (the expected value of the random variation is zero). A manager or planner should appreciate this distinction between the forecast of the expected value of the escapement and the actual observed escapement.

Some have attributed the low actual escapement in 1992 to severe drought, which would affect spring upstream migration, and a strong El Niño condition in the ocean (Futish et al. 1992). Our models predict 1992 escapements that are higher than actual. The models do not include factors related to spring flow or El Niño effects, and this may account for the difference.

The equations developed by our study apply only to the Rogue and Umpqua Rivers. If there were other rivers which had records of fish returns made in a consistent manner over a substantial time period, they too could be evaluated for use of water flow and hatchery release-data in order to forecast escapements. We have unsuccessfully searched for these in the other 26 Oregon coastal rivers and elsewhere.

Standard fisheries methods for setting harvests and forecasting abundances rely on steady state models in which the environment is assumed to be constant and the primary variables are human actions. Such methods do not consider effects of environmental variation (Mangel, et.al., 1996; Talbot, 1995). Human actions usually taken into account are mainly direct harvest, but in the Columbia River system analyses include the effects of hydroelectric and water supply dams as obstacles.

We have taken quite a different approach, using environmental variation as a way to explain variation in fish abundance. We suggest that this approach could find wider applicability. The resulting forecasting method has substantially greater specificity (i.e., specific rivers) and it yields good predictions much farther in advance (up to four years rather than three months).

While salmon have complex life cycles, the fact that they spend some of this cycle in fresh waters provides an opportunity for measurements and observations. As difficult as the problem of conserving and management salmon is, this is an advantage in comparison to attempts to manage pelagic fisheries. It is easier to count returning adult salmon than it is to count strictly pelagic fish; easier to take actions that control the habitats; easier to observe effects of these actions; and more data are available for environmental factors in streams than in the open ocean. Even so, it would seem advisable to seek better data for all fish species of commercial and recreational interest, and to attempt to develop new kinds of forecasting models that make use of environmental variation.

6.3 Specific Recommendations

Based on the results in this paper, the following actions would seem advisable:

(1) Continue to run the regressions given here each year to predict both the escapement three months in advance and three and four years in advance, and begin to integrate this method into the planning process;

(2) Continue to monitor all the variables we examined and inspect the regressions each year to see whether there is a time when the relationships begin to break down. This would indicate that some baseline condition that had previously been constant may have begun to change, and either the baseline conditions had been permanently altered or they varied frequently enough to be added as a predictive variable;

(3) Conduct additional analyses of the data presented here to discover whether other models, including ones with nonlinear responses of hatchery releases and flows, and nonlinear interactive terms, might yield improved predictive power;

(4) Consider other variables, such as land use, land cover, ocean upwelling and ocean temperatures, to determine whether any of these significantly improve the models

(5) Examine data collection methods to discern where there may be ways to improve their accuracy. Some relatively new but established technologies would allow greater detail in observations of fish migration;

(6) Examine the statistical design and the reliability of the data under present measurement methods;

(7) Conduct additional analysis of land uses, ocean currents, and illegal catch to gain insight into the slight but significant downward trend in Rogue River spring chinook escapements;

(8) Establish long term escapement measuring stations for other rivers on a statewide basis; and

(9) Develop similar relationships for other rivers.

6.4 The Need for Further Research

The forecasting models in Tables 3R and 3U are based on the jackknife analyses in Table 2. These suggest that the general method may be useful, and that further there is a need for additional research to assess the significance of other flow attributes three years or more before escapement. Prospects include the total flow during November, (the 7 day low flow rather than single day as used by the U.S.G.S), the lowest total 30 day flow during the year, minima and totals for periods other than 30 days long, fractiles other than the minimum (e.g., median daily flow during November), and nonlinear transformations (such as logarithms) of these variables.

Our statistical models do not consider the possible effects of dams on the Rogue River, including Gold Ray and Lost Creek Dams, whose effects have been evaluated by others (e.g. Cramer et al. 1985, Satterthwaite 1987). However, the data were not available to allow us to include dam effects.

7. CONCLUSIONS

We present what are, to our knowledge, the first models attempting to predict river specific returns of adult salmon based on variations in environmental factors. *The major result is* *that variations in environmental factors are good indicators of variations in adult salmon returns.* *R*iver flow in a spawning year is an important determinant of the amount of spring chinook escapement three and four years later. The minimum one day flow during November is a particularly good flow variable.

Smolts released by a hatchery are primarily negatively correlated with the numbers of wild chinook returning to spawn three and four years later. Variation in the number of hatchery fish released in a year accounts for only a small percentage of the variation of the numbers of returning adult fish three or four years later. If the purpose of hatcheries on the Rogue River is to reliably increase the return of adult fish, our analyses suggest that the hatcheries have not accomplished that goal.

Ocean troll catch three months prior correlates with escapement. However, models that do not utilize troll catch have good explanatory power, and are important because they yield good forecasts of escapement three and four years in advance.

The preliminary results support the idea that forecasting models can be useful, particularly if they utilize information known long in advance. Further collection of relevant data should be combined with development of better forecasting models.

8. ACKNOWLEDGMENTS

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