Information Report

Stock Assessment and Optimal Escapement of Coho Salmon in Three Oregon Coastal Lakes

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December 2000

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Acknowledgement

The author thanks many ODFW employees for their help in completing this report. Messrs. S. King and S. Sharr encouraged the research. Mr. S. Jacobs provided all spawning ground survey data and recommendations for using these data. Mr. J. Leppink provided freshwater harvest data, Mr. C. Melcher provided OCN ocean harvest rate data, Mr. B. Buckman provided information on coastal lakes, and Mr. M. Mill helped with the map. Messrs. S. Sharr, C. Melcher, M. Burner, and S. King reviewed and edited the manuscript. Their editing improved this paper.

Abstract

Statistical stock and recruitment analyses were conducted for coho salmon (*Oncorhynchus kisutch*) in three Oregon coastal lake basins: Siltcoos, Tahkenitch, and Tenmile lakes. Available data spanned return years 1960-1999 with complete brood data from 1960 to 1996. These data included: spawning escapement, freshwater harvest, ocean harvest rate, and ocean survival rate. Significant efforts were dedicated to assessing uncertainties. These uncertainties included measurement error in estimating spawning population, freshwater harvest, ocean harvest, and the total production, as well as uncertainty in the relationship between spawners and recruits. Large variances were discovered and they have been embodied in parameter estimation and stochastic simulation. The Ricker model was used for all three stocks with adult spawner and marine survival rate as independent variables. The analysis provided management choices on either maximum sustained yield or maximum sustained production, and on either point management or range management. The author recommends that maximum sustained production be adopted for management goals and range estimates be used for flexibility and to account for uncertainty. Specifically, the adult spawner population should be approximately 1,800-3,300 for Siltcoos Lake, 880-2,200 for Tahkenitch Lake, and 2,800-5,800 for Tenmile Lakes.

Introduction

Siltcoos, Tahkenitch and Tenmile lakes are three major freshwater lake basins along the Oregon coast. All three lakes are located on the central coast of Oregon between the Siuslaw River and the Coos River, with Siltcoos Lake and Tahkenitch Lake to the north of the Umpqua River and Tenmile Lakes to the south (Figure 1).

Siltcoos Lake is the largest lake on the Oregon coast. It has a surface area of 3,164 acres and average depth of 11 feet (Johnson et al. 1985). The drainage basin of Siltcoos Lake encompasses about 68 square miles, of which 88% are forest. There are four principal tributaries entering the lake: Woahink Creek, Fiddle Creek, Maple Creek, and Lane Creek. The lake discharges into the Pacific Ocean via the Siltcoos River.

Tahkenitch Lake has a surface area of 1,674 acres and a mean depth of 11 feet (Johnson et al. 1985). Its drainage basin covers 34 square miles and the majority (88%) of the drainage is also forested. The lake has an extremely long shoreline (25.5 miles) with arms extending up tributary valleys. Two major creeks enter the lake: Fivemile Creek and Leitel Creek.

The Tenmile Lakes basin includes 10 lakes characterized by their long and narrow shapes. These lakes vary in size from about 6 acres to over 1,600 acres (ODFW 1991). Among these lakes, Tenmile Lake and North Tenmile Lake have the largest surface area (>1,000 acres) and are the most productive.

Siltcoos, Tahkenitch, and Tenmile lakes are typical eutrophic lakes characterized by shallow depth and high productivity (ODFW 1991, Saltzman 1966). The stable physical and biological environments provide suitable habitat for juvenile coho salmon. Since the 1970s, Oregon coastal natural coho salmon (OCN) abundance in streams has significantly decreased (ODFW 1995). In contrast to coast streams, abundance of coho salmon in lake basins appears to be less variable. Strict constraints on ocean harvest of OCN coho appear to have contributed to the abundant return of coho to these lakes in recent years (B. Buckman, ODFW, Newport, personal communication). The purpose of this report is to conduct stock and recruitment assessment and provide biological escapement and harvest goals for these lakes.

Methods

Many of the data sources and methods used for analysis of stocks in Siltcoos, Tahkenitch, and Tenmile lakes are similar. Therefore, the descriptions are combined in this section. Specific descriptions are provided when differences exist in data sources and methods among these three stocks.

Estimation of escapement

Because both spawning population and recruitment are derived from escapement, escapement is the essential component in salmon stock-recruitment analysis. The methods for estimating coho escapement in Oregon coastal rivers and lakes have changed several times (Beidler and Nickelson 1980; Jacobs and Cooney 1991; Jacobs and Nickelson 1998). Escapements were estimated based on spawning ground surveys on standard index sites before 1990 and since then stratified random sampling methodology (SRS) has been implemented to select the survey sites. For coastal lake basins, peak counts of both live fish and carcasses were used to index the escapement abundance before 1985. However, estimates of the total number of fish in survey stream segments has been used since 1985. In the latter method, the total number of coho salmon spawning in a given stream segment throughout the course of the spawning season was estimated using area-under-the-curve (AUC) techniques (Beidler and Nickleson 1980; English et al. 1992; Jacobs and Cooney 1997). The formula is slightly modified here as:

$$\hat{N}_{s,i} = \frac{1}{\hat{D}} \sum_{h=1} \frac{\overline{C}_{h,s,i} t_{h,i}}{\hat{Q}_s} \qquad (1)$$

Where:
$N_{s,i}$ = total number of size *s* (adult or jack) coho salmon in stream segment *i*;(a hat indicates an estimate);
D = average stream life (days) for either adult or jack coho;
$\overline{C}_{h,s,i}$ = mean count of size *s* coho in segment *i* during period *h*;
t_{hi} = number of days in period *h* in segment *i*;
Q_s = observation efficiency, i.e., the fraction of the number of fish present in an area that are detected by the surveyor.

The mean stream life of 11.3 days has been used in AUC estimates of Oregon coho salmon spawning escapements (Jacobs and Cooney 1997). This mean stream life was based on reports of Willis 1954 and Beidler and Nickelson 1980. Willis found that stream life for both female and male coho salmon ranged from 4 to 32 days. I recovered the data from a figure in Willis' paper and estimated the mean stream life was 11.67 days and variance for the mean stream life was 0.718 (n = 51). The observation efficiency came from Solazzi's study in 1984 (Solazzi 1984):

For adult coho: $\hat{Q}_a = 0.755$, $V[\hat{Q}_a] = 0.0012$ (n = 51)

For jack coho: $\hat{Q}_j = 0.491$, $V[\hat{Q}_j] = 0.0058$ (n = 38)

At a specific stream segment, the total area under the curve can be treated as a constant (not a random variable). Since the stream life *D* and observation efficiency *Q* were estimated from independent studies, the correlation between the two variables was considered zero. Therefore the variance of $N_{s,i}$ can be obtained by a simplified Delta method (Seber 1982; Brown and Rothery 1993):

$$V[\hat{N}_{s,i}] = \left(\frac{\sum_{h=1} \overline{C}_{h,s,i} t_{h,i}}{\hat{D}\hat{Q}_s} \right)^2 \left(\frac{V[\hat{D}]}{\hat{D}^2} + \frac{V[\hat{Q}_s]}{\hat{Q}_s^{\ 2}} \right) \qquad (2)$$

Because the peak count was used as an abundance index before 1985, it must be converted to the total number of fish. Paired data between peak counts and AUC estimates from 1992 to 1997 were used to derive the relationship between the two methods:

Adult coho: $\hat{N}_{a,i} = 1.998 C_{a,i,p}$, $n = 2116$, $r^2 = 0.894$, $p < 0.001$,

Jack coho: $\hat{N}_{j,i} = 1.75 C_{j,i,p}$, $n = 2116$, $r^2 = 0.945$, $p < 0.001$.

Where $C_{s,i,p}$ is the peak count of adult (*a*) or jack (*j*) in stream segment *i*. The variance for the total number of fish in stream segment *i* before 1985 contains two components: variance from the prediction of a new $N_{s,i}$ from peak counts (Kleinbaum, Kupper and Muller 1988) and variance due to measurement errors in stream life and observation efficiency:

$$V[\hat{N}_{s,i}] = S^2_{N|C} \left[1 + \frac{1}{n} + \frac{[C_{i,p} - \overline{C}_p]^2}{(n-1)S^2_{\ C}} \right] + \left(\frac{1}{\hat{D}\hat{Q}_s} \right)^2 \left(\frac{V[\hat{D}]}{\hat{D}^2} + \frac{V[\hat{Q}_s]}{\hat{Q}_s^{\ 2}} \right) \qquad (3)$$

Where $S^2_{N|C}$ is the residual variance from the regression, $C_{i,p}$ is the peak counts in stream segment *i*, S^2_c is variance of peak counts used for the regression.

In the Siltcoos and Tahkenitch basins the total number of adults or jacks was obtained by total adult or jack density in the surveyed area multiplied by spawning habitat in that lake basin. This is different from the previous method (Jacobs and Cooney 1997). First the density and its variance were estimated as (Thompson 1992):

$$\hat{d}_{s,y} = \frac{\sum_{i=1} \hat{N}_{s,i,y}}{\sum_{i=1} G_i}$$

$$V[\hat{d}_{s,y}] = \frac{G - \sum_{i=1}^{n} G_i}{G} \frac{1}{\overline{G}^2 n(n-1)} \sum_{i=1}^{n} (\hat{N}_{s,i,y} - \hat{d}_{s,y} G_i)^2 + \frac{\sum_{i=1}^{n} V[\hat{d}_{s,i,y}]}{n} \qquad (4)$$

where
G = total square yards of spawning gravel in the lake basin;
G_i = square yards of spawning gravel in stream segment i in that lake basin.

It should be pointed out that missing data points exist in some years. Not all standard survey sites were surveyed in these years. Multivariable regression was used to estimate missing data. The number of fish in the missing survey segment was regressed over all other surveyed segments that could be used as significant predictors ($p < 0.05$). The variance from the regression was included in the total variance estimation.

The fish densities in standard survey sites were considered biased higher than the average density in the entire basin. This density should be adjusted by a correction factor to reflect the survey areas and non-survey areas. Limited random surveys have been conducted in the lake basins in recent years. The correction factor ϕ was derived as the ratio between the random survey estimate and the estimate from the above method. The total number of size s fish in year y, $N_{s,y}$, and its variance $V[N_{s,y}]$ are:

$$\hat{N}_{s,y} = \hat{d}_{s,y} G\phi \qquad \text{and} \qquad V[\hat{N}_{s,y}] = (G\phi)^2 V[\hat{d}_{s,y}] \qquad (5)$$

$\hat{N}_{a,y}$ is the total number of adult spawners in year y and can be denoted by the more familiar symbol $\hat{S}_y$ (see below). Assuming $\hat{N}_{a,y}$ follows a log-normal distribution, the number of adult spawners can be expressed as (Quinn and Deriso 1999):

$$\hat{N}_{a,y} = N_{a,y} e^u \qquad (6)$$

where $N_{a,y}$ is the actual adult spawners in year y and u is a normal random variable with expected value of 0 and variance σ^2_u.

Over the years, variance in estimated adult spawners has a two-stage structure with annual variation among the N_a plus sampling error for each estimate $\hat{N}_{a,y}$. After log-transformation the variance is:

$$V[\ln(\hat{N}_a)] = V[\ln(N_a)] + \sigma_u^2 \qquad (7)$$

where $V[\ln(N_a)]$ is the true variance for the *actual* spawners over the years, $V[\ln(\hat{N}_a)]$ the true variance of *estimated* spawners over the years, and σ_u^2 represents the actual sampling error. Estimates of these latter two variances are (CTC 1999):

$$V[\ln(\hat{N}_a)] = \frac{\sum[\ln(\hat{N}_{a,y}) - \overline{\ln(\hat{N}_a)}]^2}{n-1} \qquad (8)$$

$$\hat{\sigma}_u^2 = \frac{\sum \text{cv}^2(\hat{N}_{a,y})}{n} \qquad (9)$$

An estimate of the variation in spawning abundance across years is $V[\ln(N_a)] = V[\ln(\hat{N}_a)] - \hat{\sigma}_u^2$. The sampling error was compared to the total variance of estimated spawner abundance to determine if sampling error should be corrected for statistical stock-recruitment analysis (CTC 1999, Quinn and Deriso 1999). These variances were also used in uncertainty assessment (see below).

Estimation of recruitment

I defined the total recruitment as total coho salmon (jacks and adults) returning to the lake basin in the absence of fishing impacts. Similarly, the adult recruitment, which can be alternatively used in the stock-recruitment analysis, was the age 3 and older salmon returning to freshwater when there were no fishing impacts. Recruitment was the sum of escapement to spawning grounds, freshwater fishing impacts and ocean fishing impacts. Both freshwater and ocean fishing impacts included catch plus fishing related incidental mortality.

Freshwater harvest and terminal run

Freshwater catch was estimated from angler's voluntary reports of catch on the salmon/steelhead tag called punch cards. Only adult salmon were required to be reported on the punch cards. I examined reported catch of coho salmon from 1984 to 1994 and did not find fish with total length less than 20 inches. Variance for adult catch is:

$$V[\hat{C}_{a,y}] = \left(\frac{C_{r,y}A_{o,y}}{A_{1,y}}\right)^2 V[\hat{R}] = \left(\frac{\hat{C}_{a,y} - C_{r,y}}{\hat{R}}\right)^2 V[\hat{R}] \qquad (10)$$

Where $\hat{C}_{a,y}$ = estimated catch of adult coho salmon in year y;
$C_{r,y}$ = punch card reported catch of coho salmon in year y;
$A_{o,y}$ = number of anglers not returning punch cards for year y;
$A_{1,y}$ = number of anglers returning punch cards for year y;
R = catch ratio between anglers not returning punch cards and anglers returning punch cards.

Hicks and Calvin (1964) estimated the variance of catch ratio between anglers not returning punch cards and anglers returning punch cards as 0.00367 for salmon. This value was applied in this report.

Jacks in the catch were estimated by assuming that jack harvest rate was the same as that for adult. Adult harvest rate in freshwater $\hat{h}_{f,y}$ is:

$$\hat{h}_{f,y} = \frac{\hat{C}_{a,y}}{\hat{N}_{a,y} + \hat{C}_{a,y}} \quad . \qquad (11)$$

Where $\hat{N}_{a,y} + \hat{C}_{a,y} = \hat{T}_{a,y}$ is estimated terminal run of adult coho in year *y*. Because the escapement and catch were estimated independently, the variance for terminal run is:

$$V[\hat{T}_{a,y}] = V[\hat{N}_{a,y}] + V[\hat{C}_{a,y}] \qquad (12)$$

By using the Delta method, variance for harvest rate can be estimated as:

$$V[\hat{h}_{f,y}] = \hat{h}^2{}_{f,y}\left(\frac{V[\hat{C}_{a,y}]}{\hat{C}^2{}_{a,y}} + \frac{V[\hat{T}_{a,y}]}{\hat{T}^2{}_{a,y}}\right) - 2Cov\left(\hat{C}_{a,y}, \hat{T}_{a,y}\right)\frac{\hat{C}_{a,y}}{\hat{T}^3{}_{a,y}} . \qquad (13)$$

Where covariance between catch and terminal run was estimated for the estimated paired catch and terminal run. Now jack catch and its variance can be estimated as:

$$\hat{C}_{j,y} = \hat{N}_{j,y}\frac{\hat{h}_{f,y}}{1-\hat{h}_{f,y}} \qquad (14)$$

$$V[\hat{C}_{j,y}] \approx \left(\frac{\hat{h}_{f,y}}{1-\hat{h}_{f,y}}\right)^2 V[\hat{N}_{j,y}] \qquad (15)$$

Jack terminal run size was $\hat{T}_{j,y} = \hat{N}_{j,y} + \hat{C}_{j,y}$ with variance $V[\hat{T}_{j,y}] = V[\hat{N}_{j,y}] + V[\hat{C}_{j,y}]$

Ocean harvest and recruitment

Ocean harvest rate data came from three sources. For 1960-1969 I used OPI (Oregon Production Index) harvest rates estimated by Lawson (1992). He obtained the ocean harvest rate by reducing the OCN escapement estimation from standard index surveys by 0.33 (Method 2 in his report). This appears to be the best estimate for early year ocean fisheries and the estimations from this method were very similar to calibrated harvest rates between 1970 and 1992. Oregon coastal coho salmon escapement data from standard index surveys have been calibrated by stratified random surveys since 1970. For 1970-1992 I applied OPI ocean harvest rates based on calibrated OCN escapement. Since 1993 the ocean salmon fishing regimes have significantly changed to reduce impacts on OCN coho salmon. Therefore, specific OCN harvest rates were used for 1993-1999 (Table 4). Jack exploitation rates were estimated by assuming that contact rate was 10% of that for adults and the hooking mortality for jacks was 0.14 (C. Melcher, ODFW, personal communication).

The recruitment from brood year y spawners was obtained by expanding the terminal run to ocean abundance:

$$\hat{R}_y = \sum_{a=2}^{3} \frac{\hat{T}_{a,y}}{\prod_a (1 - H_{a,y})} \qquad (16)$$

Where $H_{a,y}$ is the ocean harvest rate of age a fish from brood year y. The variance for recruitment is:

$$V[\hat{R}_y] = \sum_{a=2}^{3} \left[\left(\frac{1}{\prod_a (1 - H_{a,y})} \right)^2 V[\hat{T}_{a,y}] \right]. \qquad (17)$$

The estimated recruitment can be expressed as $\hat{R}_y = R_y e^v$, where R_y is actual recruitment. Assuming $v \sim N(0, \sigma^2_v)$, measurement error of recruitment can be estimated as:

$$\hat{\sigma}_v^2 = \frac{\sum \mathrm{cv}^2(\hat{R}_y)}{n}. \qquad (18)$$

This measurement error was used to adjust the processor error from the model fitting (see below).

Stock-recruit relationship

Both a Beverton and Holt model and a Ricker model were fit to the estimated series of $\hat{N}_{a,y}$ and $\hat{R}_y$. Because Beverton and Holt's model has lower r^2 and higher p value, only the Ricker model was used:

$$\hat{R}_y = \hat{N}_{a,y} Exp[\ln(\alpha) - \beta \hat{N}_{a,y} + e_y] \;, \qquad (19)$$

where e_y is the log-normal error term with mean 0 and variance σ^2_e. e_y is the combination of model process error ε_y and measurement error of spawner and recruit, i.e., $e_y = \varepsilon_y + u_y +$ and $\sigma^2_e = \sigma^2_\varepsilon + \sigma^2_{uv}$. Measurement error of spawner and recruit can be approximated through the Delta method:

$$\hat{\sigma}^2_{uv,y} \approx cv^2(\hat{R}_y) + cv^2(\hat{N}_{a,y}) \qquad \text{and} \qquad \hat{\sigma}_{uv} = \frac{\sum_n \hat{\sigma}^2_{uv,y}}{n}. \qquad (20)$$

The variance of measurement error was used as weights in model fitting. The weights were the reciprocals of the estimated sampling variances for the dependent variable. The estimated process error was used to correct spawners needed for maximum sustained yield, S_{msy} (see below).

Curve fitting of this basic model was typically improved for these lake coho salmon stocks by adding an additional independent variable—marine survival rates m_y. The actual model used in this report is:

$$\hat{R}_y = \hat{N}_{a,y} Exp[\ln(\alpha) - \beta\hat{N}_{a,y} + \gamma(m_y - \overline{m}) + e_y] \qquad (21)$$

No marine survival data were available for any of these three lake coho stocks. I chose the North Umpqua hatchery coho stock as a surrogate because of its geographical proximity to these lakes. Consistent survival information were available for North Umpqua hatchery coho since brood year 1980. Survival rates before 1980 have to be estimated from other stocks. The Fall Creek hatchery coho salmon in the Alsea River was the next closest stock to these lakes and has survival data since brood year 1973. The relationship between North Umpqua hatchery stock and Alsea stock were developed for estimating the survival rates from 1973 to 1979:

$\hat{m}_{Ump,y} = 1.604 m^{0.795}{}_{Alsea,y}$ $n = 17$, $r^2 = 0.694$.

However, there was no survival information for Oregon coastal coho salmon before 1973. A simple way is to use an average survival rate for the early time period. I chose the10 year average between 1973 and 1982 (Table 4).

Estimation of management parameters

In addition to model parameters $\ln(\alpha)$, β, and γ, we are interested in spawner abundance that can produce maximum sustainable yield (S_{msy}) and maximum sustainable production (S_{msp}) and exploitation rates that support maximum sustainable yield (U_{smp}) and maximum sustainable production (U_{msp}).

Because the recruitment included both adults and jacks and jacks were assumed to contribute little in producing the next generation, recruitment should be discounted to the same unit used for spawners to estimate the S_{msy}. Let θ be the mean ratio of jacks to adults in the recruitment, S_{msy} can be obtained by iteratively solving the equation:

$$(1 - \beta\hat{S}_{msy}) Exp[\ln(\alpha) - \beta\hat{S}_{msy} + \hat{\sigma}^2_{\varepsilon}/2] = 1 + \theta \,. \qquad (22)$$

A correction $Exp(\hat{\sigma}^2{}_{\varepsilon}/2)$ for process error in the stock-recruitment relationship was used to adjust the S_{msy} (Hilborn and Walters 1992; CTC 1999). U_{msy}, S_{msp}, and U_{msp} were derived from the following formula:

$$\hat{U}_{msy} = \hat{\beta}\,\hat{S}_{msy}, \qquad \hat{S}_{msp} = \frac{1}{\hat{\beta}}, \qquad \text{and} \qquad \hat{U}_{msp} = 1-(1+\theta)Exp[1-\ln(\hat{\alpha})]. \qquad (23)$$

Uncertainty assessment: bootstrap and simulation

Measurement errors from spawner and production estimations and process errors from the stock-recruitment model resulted in uncertainty of estimated parameters. Variances for some parameters can be obtained from the original regression but variances for other parameters (e.g., S_{msy}) cannot be derived. I used bootstrapping and Monte Carlo simulation to assess uncertainty in the analysis.

For each simulation, spawner abundance was generated by $\hat{S}^*{}_y = \hat{S}_y e^u$ where u is from Equation (6) and $u \sim N(0, \hat{\sigma}_u)$. There was limited information on variability of marine survival rates for North Umpqua hatchery coho salmon. In 11 out of 17 years (brood years 1980 to 1996) two or more groups of coded-wire-tagged smolts with different codes were released. Early brood years (1980-1990) had a higher average survival rate of 2.29%, while later years (1991-1996) had a lower average survival of 0.31%. Distribution of survival has been considered to approximate a gamma distribution (Nickleson and Lawson 1998). However, variability was difficult to assess using a gamma function when survival rates are extremely low. I chose the log-normal distribution function for survival rate since the gamma and log-normal distributions often fit the same data equally well (Myers et al. 1995). The mean standard error for the log-transformed survival rates from 1980 to1996 was 0.398 and did not vary as much as survival rate itself. Therefore, I used the $SE(m)$ = 0.398 for all years. The new vector of survival was $\hat{m}^*{}_y = \hat{m}_y e^w$ where $w \sim N(0, 0.398^2)$.

The new set of dependent variable, R_y, was generated by non-parametric bootstrapping. First, the residuals were calculated as differences between observed and model (21) predicted values for R_y:

$$\delta_y = \hat{R}_y - E[\hat{R}_y]. \qquad (24)$$

A new vector of residuals $\delta^*{}_y$ was randomly drawn with replacement from the original residuals δ_y and a new vector of recruitment $R^*{}_y$ was obtained by

$$R^*{}_y = E[\hat{R}_y] + \delta^*{}_y. \qquad (25)$$

After new vectors of $S^*{}_y$, $m^*{}_y$, and $R^*{}_y$ were generated, these simulated data were fit with model (21). Simulated model parameters ($\ln(\alpha)$, β, γ, etc.) and management parameters (S_{msy}, U_{msy},

S_{msp}, U_{msy} etc.) were derived in the manner of the original analysis. One thousand of such simulations were obtained. Variances for the parameters were estimated as:

$$v(\zeta) = \frac{\sum_{b=1}^{K} (\zeta_k - \bar{\zeta}_k)^2}{K-1}, \tag{26}$$

where ζ is any derived parameter or model parameter and K is the number of simulations.

The percentile method (Efron and Tibshirani 1993) was used to provide 90% confidence intervals about parameter ζ as a range. The K values of ζ were sorted in ascending order. The lower bound was the value of ζ at the [(0.05)K+1]th place down the list; the upper bound was the [(0.95)K-1]th value.

Results

Siltcoos Lake

Spawning abundance estimation was based on surveys at five standard sites: Alder, Fiddle, Henderson, Maple, and North Prong creeks. The spawning gravel of these sites totaled 1,655 square yards while the entire basin had 6,870 square yards of spawning gravel. From 1960 to 1999 the number of adult spawners ranged from 368 to 5,953 with a mean of 2,576 (n = 37, SD = 1,283, Table 1). The coefficient of variances ($cv[N_{a,y}]$) varied from 10% to 55% with a mean of 20.5%. For the 1981 run year, the variance was extremely high because no spawning ground survey was conducted in the Siltcoos Lake basin. The only information in 1981 was the punch card catch of adult coho salmon. Terminal run and escapement were estimated from freshwater catch and average harvest rate. This exercise resulted in large variance. Large variances also occurred in years when less than five stream segments were surveyed. Abundance estimates with large variances will have less influence in the model fitting because the weights were reciprocal to the variance. With log transformation, $V[\ln(N_a)] = 0.341$, and the mean log transformed variance $\hat{\sigma}^2_u = 0.0483$. Thus, the measurement error represents about 14% of overall variation in estimated spawning abundance.

Jacks were estimated separately. The total number of jacks ranged from 113 to 2,090 with a mean of 797 (n = 37, *SD* = 538, Table 1). The coefficient of variance ($cv[N_{j,y}]$) ranged from 16% to 55% with a mean of 29% . With log transformaiton, $V[\ln(N_j)] = 0.559$, and the mean log transformed variance $\hat{\sigma}^2_u = 0.0898$. Thus measurement error represents about 16% of the overall variation in estimated jack abundance.

A few hundred adult coho salmon were typically harvested in the freshwater recreational fishery (Table 2). The maximum harvest occurred in 1984 when 1,091 adult coho were reported. Since 1993 angling for coho has been prohibited in Siltcoos Lake. During the years when the fishery was open the harvest rate varied from less than 1% to 30% with a mean = 13.5%, *SD* = 0.065. Applying this harvest rate to jacks, the average catch of jacks was 132 fish per year before 1993.

The annual ocean exploitation rate on OCN coho salmon changed significantly across years. It varied from about 0.32 to 0.90 before 1993 (Table 3). The mean exploitation rate from 1960 to 1992 was 0.69 (SD = 0.15). I estimated the total ocean abundance before fishing from 1960 to 1999 by expanding the terminal run size by the ocean exploitation rate (Figure 2). This was the recruitment assuming no fishing impacts. When expressed with respect to brood year, the total recruitment from brood years 1960 to 1996 ranged from 1,282 to 22,832 with a mean of 9,832 (Table 4). Recruits per adult spawner varied from 0.7 to 26.2 with a mean of 5.5 and standard deviation of 5.2. For adult recruits only, the ratio of recruits to spawners were 0.5 to 25.7 with a mean of 5.0 and SD of 4.9.

I conducted several model fittings to develop alternative management goals. The results presented below and in Table 4 were under the mean ocean survival condition, i.e., $m = 2.5\%$.

Model 1: Total recruitment, weighted regression, full data set (Figures 3 and 4). The estimated sampling variances for the dependent variable $\ln(R_y/S_y)$ varied over 10 times (from 0.03 to 0.32) for brood years 1960-1996. The reciprocals of these variances were used as the weight in the regression. No serious problems were detected from the residual analysis (Figures 5, 6, and 7) and no significant autocorrelation was observed among the residuals (Figure 8). However, two data points, 1989 and 1991, appeared as outliers (Figures 4, 5, and 6) although the Cook's distances were only 0.23 and 0.27, respectively. The results from this model output were preferred (Table 5).

Model 1a: Total recruitment, weighted regression, reduced data set. Brood year 1989 and 1991 were deleted from Model 1 so the total number of data points was reduced to 35. The reduction improved the model fitting. However, there was no evidence that these two years were indeed outliers. The results were: $r^2 = 0.670$, adjusted $r^2 = 0.649$, $p < 0.001$, $\ln(\alpha) = 2.692$, $\beta = 0.000486$, $\gamma = 0.136$, $S_{msy} = 1994$, $U_{msy} = 0.797$, $S_{msp} = 2058$, and $U_{msp} = 0.791$.

Model 2: Total recruitment, general regression, full data set. This exercise was similar to Model 1 except that no weights were applied in the regression. Compared to the weighted regression, the estimated S_{msy} was lower but S_{msp} was slightly higher. In fact, the r^2 was slightly better than Model 1, which indicates that large variances are not necessarily associated with poor population estimation for this data set (Table 5).

Model 2a: Total recruitment, general regression, reduced data set. This exercise used data for brood years 1973 to 1996 because no ocean survival data were available before 1973. The results were: $r^2 = 0.589$, adjusted $r^2 = 0.550$, $p < 0.001$, $\ln(\alpha) = 2.305$, $\beta = 0.000491$, $\gamma = 0.153$, $S_{msy} = 1608$, $U_{msy} = 0.749$, $S_{msp} = 2036$, and $U_{msp} = 0.691$.

Model 3: Adult recruitment only, general regression, full data set (Table 5). Because recruitment only included adults, the spawners and recruitment were in equal terms. This model simplified the parameter estimations. However, using only adults as production may result in poor model fitting if maturation rate varies significantly from brood to brood.

Cushing Model: Because measurement error represented more than 10% of total variance in the spawning abundance estimation, further correction for measurement error may be justifiable.

One method is to use the Cushing model as an approximation to Ricker's model (Quinn and Deriso 1999). This power function model can be expressed as linear models with $\ln(R_y)$ as the dependent variable and $\ln(S_y)$ as an independent variable. With this model, parameters can be corrected for measurement error. The following results suggest that this model is not appropriate for the Siltcoos stock: $r^2 = 0.252$, adjusted $r^2 = 0.208$, $p = 0.007$, $S_{msy} = 1257$.

Simulations: Total recruits, general regression, full data set. The main purpose of stochastic simulation was to assess uncertainty due to measurement errors and process errors. Bootstrap and simulation provided variance estimates for parameters whose variance cannot be derived mathematically (Table 5, Figures 9 and 10).

Comparing these exercises, for fishery management I recommend using point estimates from Model 1 and range estimates from stochastic simulations. The estimated S_{msy} and S_{msp} were similar, around 2,100 adult spawners. Using 90% confidence intervals, the ranges for S_{msy} should be about 1,600 to 2,500 and S_{msp} should be about 1,800 to 3,300. The option of managing for MSP was preferred. Under this management goal from 1960 to 1999 adult escapements were below the lower limit for 14 years, within the range for 13 years, and above the upper limit for 12 years (Figure 11).

Tahkenitch Lake

Spawning ground surveys were conducted in only two sites in Tahkenitch Lake basin, Leitel and Fivemile creeks. The spawning gravel of these two sites totaled 1,999 square yards while the entire basin had 4,402 square yards of spawning gravel. From 1960 to 1999 the adult spawners ranged from 105 to 3,122 with a mean of 968 ($n = 37$, $SD = 629$, Table 6). The coefficient of variances ($cv[N_{a,y}]$) varied from 3% to over 100% with a mean of 60%. The huge variances resulted from too few sample sizes (only 2 sites) and the densities (fish/square yard) between the two sites differed significantly. The density ratios between the Leitel and Fivemile creeks ranged from 0.15 to 14.53 with a mean of 7.11. Estimation of missing data points also contributed to the large variances. With log transformation, $V[\ln(N_a)] = 0.540$, and the mean log transformed variance $\hat{\sigma}^2_u = 0.386$. Thus, the measurement error represents about 72% of overall variation in estimated spawning abundance. The largest variance for adult spawners occurred in 1976 when only one site was surveyed and only 2 fish were observed. This data point was unreliable because it was extrapolated from a regression whose data did not cover such a low value. Huge measurement error makes the stock recruitment analysis risky. Therefore, the results in this section may be doubtful.

The total number of jacks were estimated from 62 to 1,714 with a mean of 483 ($n = 37$, $SD = 363$, Table 6). Similarly, the coefficient of variance ($cv[N_{j,y}]$) was very large, which varied from 1% to 86% with a mean of 59% . $V[\ln(N_j)] = 0.615$, and the mean log transformed variance $\hat{\sigma}^2_u = 0.380$. The measurement error represents about 62% of overall variation in estimated jack abundance.

According to punch card estimates, freshwater recreational catches of coho salmon in Tahkenitch Lake were very limited. On average, less than 50 fish (both adult and jack) were taken annually (Table 7). The maximum harvest of adult coho salmon occurred in 1984 when 123 fish were reported. Since 1993 angling for coho has also been prohibited in Tahkenitch Lake. During the years when the fishery was open the harvest rate varied from zero to 14% with a mean = 3% and *SD* = 0.03.

The total recruitment from brood years 1960 to 1996 ranged from 760 to 12,108 with a mean of 3,324 (Table 8, Figure 12). Recruits per adult spawner varied from 1.0 to 48.2 with a mean of 5.9 and standard deviation of 7.9. For adult recruits only, the ratio of recruits to spawners were 0.5 to 47.6 with a mean of 5.1 and *SD* of 7.7.

Several model fittings were conducted on Tahkenitch Lake data. The results presented below and in Table 9 were under the mean ocean survival condition, i.e., m = 2.5%.

Model 1: Total recruitment, weighted regression, full data set. The estimated sampling variances for the dependent variable $\ln(R_y/S_y)$ fluctuated by a factor of over 8, ranging from 0.19 to 1.57 with a mean of 0.65 and standard deviation of 0.67 for brood years 1960-1996. The reciprocals of these variances were used as the weight in the regression. However, when compared to the unweighted regression, using variances as weights did not improve the fitting (see below).

Model 2: Total recruitment, general regression, full data set (Figures 13 and 14). This exercise was similar to Model 1 except that no weights were applied in the regression. This model fit data better than when weights were used. The r^2, p value, and F value (13.96 vs. 10.01) were all improved, which indicated that large variances may not necessarily be associated with poor population estimation (Table 9). No serious problems were detected from the residual analysis (Figures 15, 16, and 17) and no significant autocorrelation was observed among the residuals (Figure 18).

Model 2a: Total recruitment, general regression, reduced data set. As mentioned previously, brood 1976 contained huge uncertainty because the spawner estimate may not be reliable. Since recruitment was derived from escapement, the estimated recruitment for brood year 1973 may not be reliable either. Therefore, these two data points were deleted from Model 2 to reduce the total number of data points to 35. However, this reduction did not improve the model fitting. The results were: $r^2 = 0.360$, adjusted $r^2 = 0.340$, $p = 0.0001$, $\ln(\alpha) = 2.281$, $\beta = 0.00109$, $S_{msy} = 667$, $U_{msy} = 0.733$, $S_{msp} = 921$, and $U_{msp} = 0.652$.

Model 3: Adult recruitment only, general regression, full data set (Table 9). The results from this model were very similar to results from Model 2. Using only adults as recruitment appears to be a good approximation for total production for this stock.

Simulations: Total recruits, general regression, full data set. Measurement errors in estimating spawners and recruits were included in the simulation to assess uncertainty. Large uncertainties were indicated in the simulation results (Table 9, Figures 19 and 20).

Because only two sites were surveyed in the Tahkenitch Lake basin and the survey outcomes contained large uncertainties, managers should be cautious when considering the results from this analysis. I recommend using range estimates from stochastic simulations as tentative management guidelines. Using 90% confidence intervals, the ranges for S_{msy} should be about

680 to 1,400 and S_{msp} should be about 880 to 2,200. The option of managing for MSP was preferred. Under this management goal from 1960 to 1999 adult escapements were below the lower limit for 21 years, within the range for 17 years, and above the upper limit for 2 years (Figure 21). From 1974 to 1993, escapements were below the S_{msp} range for 14 out of 20 years. Escapement increased significant since 1994 and it was above the S_{msp} range for the last two years (1998 and 1999).

Tenmile Lakes

The method for estimating spawning abundance in Tenmile Lakes slightly differs from methods for the other two lakes. Spawner density was expressed as number of fish per mile in all survey segments and was first estimated as:

$$\hat{d}_{s,y} = \frac{\sum_{i=1} \hat{N}_{s,i,y}}{\sum_{i=1} M_i}, \tag{27}$$

where
$N_{s,i,y}$ = peak counts of observed size s fish in stream segment i year y;
M_i = survey mileage in segment i.

The variance for the density is:

$$V[\hat{d}_{s,y}] = \frac{M - \sum_{i=1}^{n} M_i}{M} \frac{1}{\overline{M}^2 n(n-1)} \sum_{i=1}^{n} (\hat{N}_{s,i,y} - \hat{d}_{s,y} M_i)^2 + \frac{\sum_{i=1}^{n} V[\hat{d}_{s,i,y}]}{n}, \tag{28}$$

where
M = total miles of spawning habitat in Tenmile Lakes basin;
$\overline{M}$ = mean miles of all surveyed segments.

A mark-recapture study was conducted in Tenmile Lakes basin in 1955 (Morgan and Henry 1959). The total abundance of adults and jacks from the mark-recapture estimation was compared with peak count density in that year to derive an expansion factor υ_s for use in all other years. The total number of size s fish in year y, $N_{s,y}$ is:

$$\hat{N}_{s,y} = \hat{d}_{s,y} \hat{\upsilon}_s . \tag{29}$$

I used the υ_s of 74.0 and 151.5 for adults and jacks, respectively. From Morgan and Henry's report, variances of υ_s were estimated as 214 and 2,073 for adults and jacks, respectively. The variance for total adult or jack spawners, $V[N_{s,y}]$, is then:

$$V[\hat{N}_{s,y}] = \hat{\upsilon}_s^2 V[\hat{d}_{s,y}] + \hat{d}^2_{s,y} V[\hat{\upsilon}_s] - V[\hat{d}_{s,y}] V[\hat{\upsilon}_s] . \tag{30}$$

Spawning ground surveys were conducted in seven sites in Tenmile Lakes basin. These sites totaled 6 miles. From 1960 to 1999 the adult spawners ranged from 777 to 28,157 with a mean of 7,147 (n = 37, SD = 6,304, Table 10). The coefficient of variances ($cv[N_{a,y}]$) varied from 21% to over 89% with a mean of 32%. Estimating missing data points contributed to larger variances. With log transformation, $V[\ln(N_a)] = 0.77$, and the mean log transformed variance $\hat{\sigma}^2_u = 0.12$. Therefore, the measurement error represents about 15% of overall variation in estimated spawning abundance.

A large proportion of jacks was observed on the spawning grounds in Tenmile Lakes. The total number of jacks were estimated from 732 to 62,721 with a mean of 9,523 (n = 37, *SD* = 12,588, Table 10). The ratio of jacks to adults averaged 41.6% for brood years 1960 to 1996, which was much larger than the observed ratios in Siltcoos and Tahkenitch lakes. The coefficient of variance ($cv[N_{j,y}]$) was very large, which varied from 31% to 492% with a mean of 82%. Large variance occurred in seven years when not all standard index sites were surveyed. If variances for these years were not included, the mean $cv[N_{j,y}]$ was only 38%, and the mean log transformed variance $\hat{\sigma}^2_u = 0.15$. Since jack escapement fluctuated greatly from year to year ($V[\ln(N_j)] = 1.31$), the measurement error represents only about 12% of overall variation in estimated jack abundance

Abundance in Tenmile Lakes can be divided into two distinguishable time periods (Figure 22). High abundance was observed from 1955 to 1973 when adult spawners ranged from about 5,700 to 42,000 with a mean of 16,500. Mean number of jacks during this period was about 23,500 (4,600 to 62,700). Escapement has declined dramatically since 1974. From 1974 to 1999 adult spawners averaged only 3,453 (777 to 7,581). The mean number of jacks during recent period fell to 2,865 (732 to 6,491).

Freshwater sport catches of coho salmon in Tenmile Lakes declined along with the terminal run into the lakes. From 1960 to 1999 on average, about 240 adult and 370 jacks were harvested annually (Table 11). During the years when the fishery was open the harvest rate varied from zero to 15% with a mean = 4% and *SD* = 0.03.

The total production from brood years 1960 to 1996 ranged from approximately 5,300 to 232,700 with a mean of 34,200 (Table 12). Recruits per adult spawner varied from 1.3 to 29.2 with a mean of 5.4 and standard deviation of 5.8. When limited to adult recruits, the ratio of recruits to spawners was 0.9 to 20.8 with a mean of 4.0 and *SD* of 4.2.

Because the escapement and production varied dramatically between the two time periods, I performed the statistical analysis of stock-recruit relationship accordingly. First, the full data set from brood years 1960 to 1996 was used to explore the potential productivity and carrying capacity in the Tenmile Lakes system. Second, because of the dramatic decline in abundance, only the recent time frame (brood years 1974 to 1996) was used to develop optimal escapement under the current condition (Table 13).

Model 1: Total recruitment, weighted regression, full data set (brood years 1960 – 1996). As expected, the relationship between $Ln(R_y/S_y)$ and S_y was poor (compared to a shorter more recent time frame, see below). The F value was only 6.289 and the adjusted r^2 was only 0.227.

According to the results from this model output the carrying capacity for coho salmon in the basin was huge. This basin can support approximately 24,900 adult spawners for maximum sustained production and maximum adult escapement can be as high as 34,600. These numbers seem implausible for a small basin with less than 20 miles of spawning habitat. However, the mark-recapture study in 1955-1956 indicated that approximately 42,000 adults and 36,000 jacks had indeed escaped ocean fisheries into Tenmile Creek (Morgan and Henry 1959).

Model 2: Total recruitment, weighted regression, reduced dataset (brood years 1974-1996, Figures 23 and 24). Spawning abundance and production were more homogenous during this shorter time period and the model fit these data better than Model 1. Note that survival rate was not included as an independent variable because it was not significant in the shorter time period ($p = 0.948$). The r^2, p value, and F value (22.26 vs. 6.29) were all improved (Table 13). No serious problems were detected from the residual analysis (Figures 25 and 26) and no significant autocorrelation occurred among the residuals (Figure 27).

Model 3: Adult recruitment only, weighted regression, brood years 1974 - 1996. The model resulted in a slightly lower S_{msy} and S_{msp} and slightly higher U_{msy} and U_{msp}.

Simulations: Total recruits, general regression, brood years 1974 - 1996. The mean S_{msy} and S_{msp} were similar to the original regression (Model 2). These results indicate that the original analysis had low bias (Table 13, Figures 28 and 29).

Considering the historical escapements, Tenmile Lakes basin has the potential to support much higher spawning population. Therefore, I recommend using range estimates from stochastic simulations as tentative management guidelines. Using 90% confidence intervals, the ranges for S_{msy} should be about 2,100 to 3,500 and S_{msp} should be about 2,800 to 5,800. The option for managing MSP was preferred. Under this management goal from 1974 to 1999 adult escapements were below the lower limit for 9 years, within the range for 15 years, and above the upper limit for 2 years (Figure 30). Since 1993 escapements have all been within or above the S_{msp} range.

Discussion

Stock recruitment analyses have been conducted previously for Oregon coastal coho to develop optimal escapement goals for stock aggregates (Beidler, Nickelson, and McGie 1980; McGie 1986). However, no analysis has been attempted for an individual stock and previous studies have not included uncertainties in the analysis. Ignoring uncertainty assessment is common in previous salmon stock-recruitment analyses for Oregon stocks. Although Zhou and Williams (1999 and 2000) applied bootstrapping technique to evaluate uncertainty in the parameters of chinook salmon stock-recruitment, they did not estimate all measurement errors in spawner and production due to data limitations. The importance of including uncertainty in fishery data analysis has been increasingly recognized (Francis and Shotton 1997). Ludwig and Walters (1981) stated that "Estimates of numbers of spawners and recruits are of little value unless the accuracy of the estimates is also assessed. There is a parallel principle in the statistical estimation of model parameters: the statistical estimates are of little value unless they are accompanied by estimates of their accuracy." When measurement error is taken into account in stock-recruitment analysis, much higher, or at least more variable, spawning runs should be required to achieve management goals (Ludwig and Walters 1981). In this report I devoted significant efforts to assess uncertainties in spawning abundance, production, and the stock-recruitment models.

It is not surprising that large measurement error existed in these three lake coho stocks. Measurement error in escapement estimates consisted of several components: observation error in spawning ground surveys, variation of stream life when using the AUC method, converting peak count indexes to AUC estimates, higher variation in fish density between survey areas, and variance in estimating missing data points. To eliminate the last component, I recommend conducting spawning ground surveys for all standard index sites every year when possible. Because these survey sites were not chosen by statistical design, the same sites should be used for estimating total abundance. Excluding some areas will result in inconsistent biases over time. The average coefficient of variance for adult spawners was over 20% and 30% for Siltcoos stock and Tenmile Lakes stock, respectively. Fortunately, estimated spawning populations also changed significantly from year to year. This allowed statistical stock-recruitment analysis to be feasible even when measurement error was high. However, variances in escapement estimates for the Tahkenitch Lake stock were huge, mainly due to few survey sites. More caution should be taken when using the results for the Tahkenitch stock. On the other hand, because annual densities in one site (Leitel Creek) were consistently higher than the other site (Fivemile Creek), variance may be reduced significantly by slightly increasing sample sizes and estimating the total abundance using a stratifying method.

Among the three stocks, Tenmile Lakes coho appeared to be less productive than Siltcoos and Tahkenitch stocks. The number of spawners in the Tenmile Lakes drainage changed dramatically during the early 1970s. Predation on coho fry by other fish species may have caused this dramatic change and reduced the productivity of this stock (Reimers 1989). Reimers noted that the coho population quickly declined in the early 1970s as the population of bluegill *Leponis macrochirus* and brown bullhead *Ictalurs nebulosus* rebuilt in the lakes and after the largemouth bass *Micropterus salmoides* was introduced in 1971. Because of high predation in the lakes, the natural production of wild smolts was limited to those fry that remained in the tributary streams for rearing. Therefore, until inter-species interactions diminish it is appropriate to use the shorter time period from 1974 for the analysis in this report.

In this report I recommend maximum sustainable production as management goals for coho salmon in Oregon coastal lakes. Optimal escapements are those sufficient to fully realize the biological potential of the freshwater habitat, thereby maximizing smolt production (Knudsen 1999). MSP management concept is more conservative than MSY management. When escapement goals are developed by using stock/recruitment analysis, MSP should be preferred over MSY. This is because inaccurate measurements of spawning abundance and production and uncertainties in the relationship between stock/recruit may overestimate harvest rates and underestimate optimal stock size (Hilborn and Walters 1992; NRC 1996). In addition, as Oregon coastal coho salmon populations are depressed, biological, ecological, social, and economical values should all be considered when managing this species rather than focus on fishery harvest.

Abundance increased in recent years in all three lake basins. According to this analysis, escapements were above MSP goal range for the past one or two years in all lakes. If these lake coho stocks are viewed in isolation from other OCN stocks, it may appear that these stocks provide surplus for freshwater harvest. However, it may not be prudent to do so when considering the entire OCN status. The National Marine Services (NMFS) has identified the coho salmon from Cape Blanco to the mouth of Columbia River as one evolutionarily significant unit (ESU), which includes these three lake populations (Weitkamp et al. 1999). OCN coho spawning escapements have been severely depressed since the 1970s and in 1998 NMFS listed the ESU as threatened under the Endangered Species Act. The relatively healthy populations in the stable lake system may help rebuild coho salmon in Oregon coastal rivers by straying and metapopulation mechanism (Nicholas and Dyke 1982; Quinn 1993; Sandercock 1991; Young 1999).

The combined results for the three lake basins yield a 90% confidence interval for S_{msp} of 5,500 – 11,400 adult spawners. Recently, a habitat based model has been developed to assess the spawner escapement needed for individual basins and aggregates (Nickelson 1998). This habitat based model suggests that 8,000 spawners are needed for these lake basins. This estimate appears to be very reasonable since it is at about the middle of the S_{msp} range. In the “Tenmile Basin Fish Management Plan” (ODFW 1991), the objective for managing coho salmon was to maintain the 15-year (1974-1989) average natural spawning population of 3,867 adults. This goals is also within the range of S_{msp} for the basin. However, the average population during 1974-1989 was about 2,700 adults based on estimations in this report and in the spawning ground survey reports (Jacobs and Cooney 1997). According to this analysis, 2,700 adult spawners are very close to the point estimate of S_{msy} for the Tenmile Lakes basin. However, more spawners are needed for the MSP management goal.

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Table 1. Escapements of coho salmon in Siltcoos Lake, 1960-1999. The variances resulted from multi-stages: converting peak count index to AUC estimate, variance due to stream life and observation efficiency, missing survey site estimation, and variability among survey sites.

	Adults			Jacks		
Run year	$N_{a,y}$	$SE[N_{a,y}]$	$cv[N_{a,y}]$	$N_{j,y}$	$SE[N_{j,y}]$	$cv[N_{j,y}]$
1960	1,567	258	16.5%	479	101	21.0%
1961	3,357	337	10.0%	1,178	220	18.7%
1962	4,299	999	23.2%	728	372	51.1%
1963	3,494	585	16.7%	2,056	582	28.3%
1964	3,915	712	18.2%	645	203	31.5%
1965	2,264	284	12.5%	1,114	414	37.2%
1966	5,122	800	15.6%	568	164	28.9%
1967	2,078	495	23.8%	932	264	28.3%
1968	2,128	369	17.3%	471	129	27.4%
1969	1,560	297	19.0%	1,938	586	30.2%
1970	3,723	936	25.1%	942	291	30.8%
1971	1,594	389	24.4%	257	41	16.1%
1972	1,849	286	15.5%	1,264	222	17.6%
1973	2,705	428	15.8%	792	162	20.4%
1974	1,433	212	14.8%	1,917	804	42.0%
1975	2,697	518	19.2%	696	150	21.6%
1976	1,722	404	23.5%	412	117	28.4%
1977	1,312	182	13.9%	359	70	19.5%
1978	749	223	29.8%	124	49	39.7%
1979	2,208	322	14.6%	113	41	36.3%
1980	1,645	333	20.3%	300	59	19.7%
1981	3,108	1,723	55.4%	1,141	632	55.4%
1982	1,162	312	26.8%	311	112	36.1%
1983	636	198	31.1%	739	297	40.2%
1984	5,953	715	12.0%	1,082	271	25.0%
1985	3,212	724	22.5%	1,212	285	23.5%
1986	3,986	426	10.7%	2,090	376	18.0%
1987	1,555	450	29.0%	238	69	28.9%
1988	2,468	420	17.0%	283	87	30.6%
1989	1,963	364	18.6%	651	178	27.3%
1990	1,529	310	20.3%	419	98	23.3%
1991	2,730	329	12.1%	317	104	32.9%
1992	368	36	9.8%	187	58	31.0%
1993	3,415	588	17.2%	402	82	20.4%
1994	1,345	317	23.6%	731	160	21.9%
1995	4,240	867	20.5%	923	257	27.8%
1996	4,502	868	19.3%	1,405	281	20.0%
1997	2,501	842	33.7%	340	125	36.9%
1998	2,943	712	24.2%	963	239	24.8%
1999	4,001	982	24.6%	1,168	324	27.8%
Mean	2,576	514	20.5%	797	227	28.7%
SD	1,283	316	8.2%	538	177	8.9%

Table 2. Coho salmon freshwater harvests and terminal runs in Siltcoos Lake basin, 1960-1999.

Run	Adult catch		Jack catch		Adult terminal run		Jack terminal run		Harvest rate	
year	$C_{a,y}$	$SE[C_{a,y}]$	$C_{j,y}$	$SE[C_{j,y}]$	$T_{a,y}$	$SE[T_{a,y}]$	$T_{j,y}$	$SE[T_{j,y}]$	$h_{f,y}$	$SE[h_{f,y}]$
1960	340	20	104	22	1,906	259	583	103	0.18	0.03
1961	620	36	218	41	3,978	339	1,396	224	0.16	0.02
1962	500	30	85	43	4,799	1000	813	375	0.10	0.02
1963	867	52	510	144	4,360	587	2,566	600	0.20	0.03
1964	365	22	60	19	4,280	712	705	204	0.09	0.02
1965	339	19	167	62	2,603	284	1,281	419	0.13	0.02
1966	842	49	93	27	5,964	801	661	166	0.14	0.02
1967	286	18	128	36	2,363	495	1,060	266	0.12	0.03
1968	927	55	205	56	3,056	373	676	141	0.30	0.04
1969	371	21	461	139	1,931	298	2,399	602	0.19	0.03
1970	207	12	52	16	3,930	936	995	291	0.05	0.01
1971	100	6	16	3	1,694	389	273	41	0.06	0.01
1972	373	25	255	45	2,222	287	1,519	226	0.17	0.02
1973	280	17	82	17	2,985	429	874	163	0.09	0.01
1974	244	15	326	137	1,677	213	2,243	816	0.15	0.02
1975	413	26	107	23	3,110	518	803	152	0.13	0.02
1976	210	13	50	14	1,932	405	462	118	0.11	0.02
1977	134	7	37	7	1,446	182	396	70	0.09	0.01
1978	153	9	25	10	902	224	150	50	0.17	0.04
1979	3	0	0	0	2,211	322	114	41	0.00	0.00
1980	286	17	52	10	1,931	334	352	60	0.15	0.03
1981	485	31	178	11	3,593	1746	1,319	641	0.14	0.07
1982	360	22	96	35	1,522	312	407	117	0.24	0.05
1983	272	16	316	127	908	199	1,055	323	0.30	0.07
1984	1,091	66	198	50	7,044	718	1,280	275	0.15	0.02
1985	236	15	89	21	3,448	724	1,301	285	0.07	0.01
1986	398	25	209	38	4,384	427	2,299	378	0.09	0.01
1987	121	9	19	5	1,676	450	256	69	0.07	0.02
1988	358	26	41	13	2,826	421	324	88	0.13	0.02
1989	184	13	61	17	2,147	364	712	179	0.09	0.02
1990	202	14	55	13	1,731	311	475	99	0.12	0.02
1991	248	16	29	9	2,978	330	346	105	0.08	0.01
1992	85	6	43	13	453	37	230	60	0.19	0.02
1993					3,415	588	402	82		
1994					1,345	317	731	160		
1995					4,240	867	923	257		
1996					4,502	868	1,405	281		
1997					2,501	842	340	125		
1998					2,943	712	963	239		
1999					4,001	982	1,168	324		
Mean	361	22	132	37	2,873	515	906	230	0.13	0.02
SD	253	15	125	41	1,408	318	632	180	0.07	0.01

Table 3. Estimated adult and jack ocean harvest rates for Oregon coastal coho salmon, 1960-1999.

				Harvest rate used	
Run year	OPI SRS	OPI Lawson	OCN	Adult	Jack
1960		0.71		0.710	0.010
1961		0.73		0.730	0.010
1962		0.68		0.680	0.010
1963		0.80		0.800	0.011
1964		0.70		0.700	0.010
1965		0.71		0.710	0.010
1966		0.64		0.640	0.009
1967		0.73		0.730	0.010
1968		0.77		0.770	0.011
1969		0.70		0.700	0.010
1970	0.652	0.64		0.652	0.009
1971	0.825	0.81		0.825	0.012
1972	0.843	0.83		0.843	0.012
1973	0.819	0.81		0.819	0.011
1974	0.835	0.83		0.835	0.012
1975	0.814	0.80		0.814	0.011
1976	0.899	0.89		0.899	0.013
1977	0.888	0.88		0.888	0.012
1978	0.825	0.81		0.825	0.012
1979	0.794	0.78		0.794	0.011
1980	0.731	0.72		0.731	0.010
1981	0.811	0.81		0.811	0.011
1982	0.616	0.62		0.616	0.009
1983	0.789	0.80		0.789	0.011
1984	0.320	0.31		0.320	0.004
1985	0.432	0.43		0.432	0.006
1986	0.335	0.33		0.335	0.005
1987	0.599	0.59		0.599	0.008
1988	0.565	0.56		0.565	0.008
1989	0.553	0.54		0.553	0.008
1990	0.689	0.67		0.689	0.010
1991	0.454	0.45		0.454	0.006
1992	0.511			0.511	0.007
1993	0.423		0.179	0.179	0.003
1994	0.023		0.068	0.068	0.001
1995	0.226		0.124	0.124	0.002
1996	0.143		0.083	0.083	0.001
1997	0.123		0.124	0.124	0.002
1998	0.064		0.078	0.078	0.001
1999	0.087		0.076	0.076	0.001
Mean	0.556	0.690	0.105	0.588	0.008
SD	0.280	0.149	0.040	0.264	0.004

Table 4. Spawners and recruitment of coho salmon in Siltcoos Lake, brood years 1960-1996. The ocean survival rates were estimated from coded-wire-tagged North Umpqua River hatchery coho.

Brood year	Spawner	Adult recruits			Total recruits			Survival	
y	S_y	$R_{a,y}$	$SE[R_{a,y}]$	$Ln(R_{a,y}/S_y)$	$R_{t,y}$	$SE[R_{t,y}]$	$Ln(R_{t,y}/S_y)$	m_y	index
1960	1,567	22,011	2,963	2.64	22,832	2,987	2.68	3.20	0.70
1961	3,357	14,427	2,400	1.46	17,022	2,476	1.62	3.20	0.70
1962	4,299	9,066	990	0.75	9,778	1,011	0.82	3.20	0.70
1963	3,494	16,732	2,247	1.57	18,026	2,287	1.64	3.20	0.70
1964	3,915	8,832	1,850	0.81	9,499	1,858	0.89	3.20	0.70
1965	2,264	13,424	1,640	1.78	14,494	1,662	1.86	3.20	0.70
1966	5,122	6,508	1,003	0.24	7,192	1,013	0.34	3.20	0.70
1967	2,078	11,406	2,717	1.70	13,829	2,784	1.90	3.20	0.70
1968	2,128	9,750	2,239	1.52	10,754	2,258	1.62	3.20	0.70
1969	1,560	14,320	1,853	2.22	14,596	1,853	2.24	3.20	0.70
1970	3,723	16,718	2,401	1.50	18,255	2,412	1.59	3.20	0.70
1971	1,594	10,303	1,308	1.87	11,188	1,319	1.95	3.20	0.70
1972	1,849	16,934	2,822	2.21	19,203	2,940	2.34	3.20	0.70
1973	2,705	19,330	4,047	1.97	20,142	4,050	2.01	1.21	-1.29
1974	1,433	13,073	1,645	2.21	13,541	1,649	2.25	0.87	-1.63
1975	2,697	5,227	1,296	0.66	5,628	1,298	0.74	2.59	0.09
1976	1,722	10,884	1,584	1.84	11,036	1,585	1.86	5.45	2.95
1977	1,312	7,247	1,253	1.71	7,362	1,254	1.73	3.70	1.20
1978	749	19,241	9,350	3.25	19,597	9,351	3.27	6.57	4.06
1979	2,208	4,006	822	0.60	5,340	1,047	0.88	3.68	1.18
1980	1,645	4,340	949	0.97	4,751	957	1.06	3.71	1.20
1981	3,108	10,469	1,067	1.21	11,536	1,116	1.31	2.46	-0.05
1982	1,162	6,097	1,279	1.66	7,382	1,309	1.85	1.82	-0.68
1983	636	6,628	646	2.34	7,937	707	2.52	2.78	0.28
1984	5,953	4,200	1,129	-0.35	6,509	1,191	0.09	4.45	1.95
1985	3,212	6,546	975	0.71	6,805	978	0.75	1.53	-0.97
1986	3,986	4,841	822	0.19	5,168	826	0.26	1.62	-0.88
1987	1,555	5,616	1,008	1.28	6,334	1,024	1.40	1.93	-0.57
1988	2,468	5,506	610	0.80	5,985	618	0.89	2.12	-0.39
1989	1,963	934	75	-0.74	1,282	130	-0.43	1.59	-0.91
1990	1,529	4,191	721	1.01	4,423	724	1.06	1.15	-1.36
1991	2,730	1,446	341	-0.64	1,849	351	-0.39	0.63	-1.88
1992	368	4,845	991	2.58	5,576	1,004	2.72	0.40	-2.10
1993	3,415	4,917	948	0.36	5,842	983	0.54	0.18	-2.33
1994	1,345	2,859	963	0.75	4,265	1,003	1.15	0.30	-2.20
1995	4,240	3,198	774	-0.28	3,538	784	-0.18	0.28	-2.22
1996	4,502	4,334	1,064	-0.04	5,298	1,091	0.16	0.07	-2.44
Mean	2,529	8,930	1,643	1.20	9,832	1,673	1.32	2.50	0.00
SD	1,312	5,521	1,542	0.96	5,716	1,539	0.91	1.48	1.48

Table 5. Parameter estimates from selected models for Siltcoos Lake coho salmon. The basic model is: $\hat{R}_y = \hat{N}_{a,y} Exp[\ln(\alpha) - \beta\hat{N}_{a,y} + \gamma(m_y - \overline{m}) + e_y]$ where R_y is total recruits, $N_{a,y}$ is adult spawners and m_y is marine survival rate.

Parameters	Point est.	SE	p value	Lower 90% CI	Upper 90% CI
Model 1: Total recruits, weighted regression, full dataset (37 broods)					
Model performance: r^2 = 0.517		Adjusted r^2 = 0.489		p < 0.001	
ln(α)	2.541	0.243	<0.001	2.131	2.951
β	0.000471	0.000083	<0.001	0.000331	0.000611
γ	0.222	0.082	0.011	0.084	0.360
S_{msy}	2108				
U_{msy}	0.758				
S_{msp}	2123				
U_{msp}	0.756				
Model 2: Total recruits, general regression					
Model performance: r^2 = 0.580		Adjusted r^2 = 0.556		p < 0.001	
ln(α)	2.460	0.219	<0.001	2.090	2.830
β	0.000449	0.000077	<0.001	0.000319	0.000579
γ	0.223	0.069	0.003	0.107	0.338
S_{msy}	1802				
U_{msy}	0.781				
S_{msp}	2227				
U_{msp}	0.735				
Model 3: Adult recruits only, general regression					
Model performance: r^2 = 0.565		Adjusted r^2 = 0.539		p < 0.001	
ln(α)	2.369	0.243	<0.001	1.958	2.779
β	0.000463	0.000083	<0.001	0.000322	0.000603
γ	0.238	0.082	0.003	0.099	0.376
S_{msy}	1773				
U_{msy}	0.787				
S_{msp}	2162				
U_{msp}	0.746				
Simulation: Total recruits, general regression					
ln(α)	2.420	0.278		1.601	2.530
β	0.000424	0.0000749		0.000302	0.000549
γ	0.129	0.059		0.032	0.227
S_{msy}	1949	298		1550	2502
U_{msy}	0.770	0.043		0.695	0.831
S_{msp}	2436	472		1822	3315
U_{msp}	0.753	0.056		0.655	0.829

Table 6. Escapements of coho salmon in Tahkenitch Lake, 1960-1999. Only two survey sites and significant fish density difference between the two sites resulted in huge variances.

	Adults			Jacks		
Run year	$N_{a,y}$	$SE[N_{a,y}]$	$cv[N_{a,y}]$	$N_{j,y}$	$SE[N_{j,y}]$	$cv[N_{j,y}]$
1960	759	458	60.3%	424	315	74.1%
1961	1,486	994	66.9%	295	172	58.5%
1962	1,485	1,020	68.7%	189	85	45.2%
1963	682	288	42.2%	366	184	50.2%
1964	1,849	730	39.5%	398	171	42.9%
1965	1,367	689	50.4%	454	213	46.9%
1966	1,150	740	64.3%	368	289	78.6%
1967	821	649	79.1%	615	432	70.3%
1968	595	297	50.0%	135	67	49.4%
1969	821	592	72.0%	863	680	78.8%
1970	1,409	993	70.5%	651	539	82.9%
1971	721	442	61.3%	83	72	86.1%
1972	477	198	41.5%	559	300	53.6%
1973	2,027	1,480	73.0%	401	243	60.5%
1974	582	415	71.3%	521	259	49.7%
1975	349	114	32.7%	920	689	74.9%
1976	105	111	105.6%	82	1	1.3%
1977	786	514	65.3%	176	74	42.3%
1978	132	106	80.2%	62	17	27.9%
1979	1,017	694	68.2%	169	69	40.7%
1980	406	227	55.9%	163	64	39.1%
1981	227	184	80.8%	103	83	80.8%
1982	1,210	845	69.8%	559	381	68.2%
1983	647	406	62.8%	1,446	1,093	75.6%
1984	1,360	963	70.8%	546	371	68.0%
1985	347	146	42.2%	233	193	82.7%
1986	955	640	67.0%	457	299	65.6%
1987	495	304	61.5%	262	147	55.8%
1988	449	208	46.3%	160	132	82.6%
1989	451	249	55.2%	472	241	51.1%
1990	899	514	57.2%	796	669	84.0%
1991	1,007	646	64.2%	210	95	45.2%
1992	264	8	2.9%	641	138	21.4%
1993	791	415	52.5%	192	111	57.5%
1994	880	572	65.0%	420	259	61.6%
1995	1,348	702	52.1%	475	236	49.6%
1996	1,348	515	38.2%	953	664	69.7%
1997	1,539	923	60.0%	805	407	50.5%
1998	2,334	1,483	63.5%	991	726	73.3%
1999	3,122	2,076	66.5%	1,714	1,274	74.3%
Mean	968	589	59.9%	483	311	59.3%
SD	629	425	16.7%	363	286	18.9%

Table 7. Coho salmon freshwater harvests and terminal runs in Tahkenitch Lake basin, 1960-1999.

Run	Adult catch		Jack catch		Adult terminal run		Jack terminal run		Harvest rate	
year	$C_{a,y}$	$SE[C_{a,y}]$	$C_{j,y}$	$SE[C_{j,y}]$	$T_{a,y}$	$SE[T_{a,y}]$	$T_{j,y}$	$SE[T_{j,y}]$	$h_{f,y}$	$SE[h_{f,y}]$
1960	28	2	16	12	787	458	440	315	0.04	0.02
1961	62	4	12	7	1,548	994	307	172	0.04	0.03
1962	48	3	6	3	1,532	1020	195	85	0.03	0.02
1963	92	6	49	25	775	288	415	185	0.12	0.04
1964	31	2	7	3	1,880	730	405	171	0.02	0.01
1965	28	2	9	4	1,395	689	463	213	0.02	0.01
1966	89	6	29	22	1,239	740	396	290	0.07	0.04
1967	21	1	16	11	842	649	631	432	0.03	0.02
1968	100	7	23	11	695	297	158	68	0.14	0.06
1969	69	4	73	57	890	592	936	683	0.08	0.05
1970	23	2	11	9	1,432	993	661	539	0.02	0.01
1971	53	4	6	5	774	442	89	72	0.07	0.04
1972	19	1	22	12	496	198	582	300	0.04	0.02
1973	30	2	6	4	2,057	1480	407	243	0.01	0.01
1974	8	1	7	4	590	415	528	259	0.01	0.01
1975	4	0	11	8	353	114	931	689	0.01	0.00
1976	4	0	3	0	109	111	85	1	0.04	0.04
1977	11	1	2	1	797	514	178	74	0.01	0.01
1978	3	0	1	0	135	106	63	17	0.02	0.02
1979	0	0	0	0	1,017	694	169	69	0.00	0.00
1980	0	0	0	0	406	227	163	64	0.00	0.00
1981	8	1	4	0	235	184	106	83	0.00	0.00
1982	0	0	0	0	1,210	845	559	381	0.00	0.00
1983	0	0	0	0	647	406	1,446	1093	0.00	0.00
1984	123	8	49	34	1,483	963	595	372	0.08	0.05
1985	12	1	8	7	359	146	241	193	0.03	0.01
1986	47	3	22	15	1,002	640	479	300	0.05	0.03
1987	5	0	3	1	500	304	265	147	0.01	0.01
1988	0	0	0	0	449	208	160	132	0.00	0.00
1989	11	1	12	6	462	249	484	241	0.02	0.01
1990	19	1	17	14	918	514	813	669	0.02	0.01
1991	30	2	6	3	1,037	646	216	95	0.03	0.02
1992	0	0	0	0	264	8	641	138	0.00	0.00
1993					791	415	192	111	0.00	0.00
1994					880	572	420	259	0.00	0.00
1995					1,348	702	475	236	0.00	0.00
1996					1,348	515	953	664	0.00	0.00
1997					1,539	923	805	407	0.00	0.00
1998					2,334	1483	991	726	0.00	0.00
1999					3,122	2076	1,714	1274	0.00	0.00
Mean	30	2	13	8	992	589	494	312	0.03	0.02
SD	33	2	16	12	632	425	365	286	0.03	0.02

Table 8. Spawners and recruitment of coho salmon in Tahkenitch Lake, brood years 1960-1996. The ocean survival rates were estimated from coded-wire-tagged North Umpqua River hatchery coho.

Brood year	Spawner	Adult recruits			Total recruits			Survival	
y	S_y	$R_{a,y}$	$SE[R_{a,y}]$	$Ln(R_{a,y}/S_y)$	$R_{t,y}$	$SE[R_{t,y}]$	$Ln(R_{t,y}/S_y)$	m_y	index
1960	759	3,911	1,453	1.64	4,108	1,455	1.69	3.20	0.70
1961	1,486	6,339	2,461	1.45	6,759	2,468	1.51	3.20	0.70
1962	1,485	4,859	2,401	1.19	5,268	2,407	1.27	3.20	0.70
1963	682	3,476	2,075	1.63	3,944	2,086	1.75	3.20	0.70
1964	1,849	3,147	2,427	0.53	3,547	2,444	0.65	3.20	0.70
1965	1,367	3,051	1,307	0.80	3,688	1,378	0.99	3.20	0.70
1966	1,150	3,000	1,994	0.96	3,159	1,995	1.01	3.20	0.70
1967	821	4,157	2,882	1.62	5,102	2,963	1.83	3.20	0.70
1968	595	4,452	2,541	2.01	5,120	2,599	2.15	3.20	0.70
1969	821	3,196	1,275	1.36	3,287	1,277	1.39	3.20	0.70
1970	1,409	11,520	8,290	2.10	12,108	8,296	2.15	3.20	0.70
1971	721	3,627	2,549	1.62	4,039	2,561	1.72	3.20	0.70
1972	477	1,924	622	1.40	2,458	675	1.64	3.20	0.70
1973	2,027	1,093	1,112	-0.62	2,035	1,312	0.00	1.21	-1.29
1974	582	7,211	4,645	2.52	7,297	4,645	2.53	0.87	-1.63
1975	349	783	614	0.81	964	619	1.01	2.59	0.09
1976	105	5,007	3,414	3.86	5,071	3,414	3.87	5.45	2.95
1977	786	1,522	851	0.66	1,694	854	0.77	3.70	1.20
1978	132	1,260	985	2.26	1,424	987	2.38	6.57	4.06
1979	1,017	3,186	2,225	1.14	3,294	2,227	1.18	3.68	1.18
1980	406	3,093	1,941	2.03	3,657	1,979	2.20	3.71	1.20
1981	227	2,205	1,432	2.27	3,667	1,809	2.78	2.46	-0.05
1982	1,210	635	259	-0.65	1,232	455	0.02	1.82	-0.68
1983	647	1,515	968	0.85	1,758	987	1.00	2.78	0.28
1984	1,360	1,253	762	-0.08	1,734	820	0.24	4.45	1.95
1985	347	1,041	482	1.10	1,308	504	1.33	1.53	-0.97
1986	955	1,042	562	0.09	1,204	577	0.23	1.62	-0.88
1987	495	2,978	1,668	1.79	3,465	1,685	1.95	1.93	-0.57
1988	449	1,917	1,195	1.45	2,737	1,372	1.81	2.12	-0.39
1989	451	543	16	0.18	760	97	0.52	1.59	-0.91
1990	899	970	510	0.08	1,616	528	0.59	1.15	-1.36
1991	1,007	946	615	-0.06	1,139	625	0.12	0.63	-1.88
1992	264	1,540	802	1.77	1,960	843	2.01	0.40	-2.10
1993	791	1,473	562	0.62	1,949	610	0.90	0.18	-2.33
1994	880	1,759	1,055	0.69	2,714	1,248	1.13	0.30	-2.20
1995	1,348	2,536	1,611	0.63	3,342	1,662	0.91	0.28	-2.22
1996	1,348	3,383	2,249	0.92	4,375	2,363	1.18	0.07	-2.44
Mean	857	2,853	1,698	1.15	3,324	1,752	1.36	2.50	0.00
SD	476	2,168	1,483	0.92	2,185	1,469	0.84	1.48	1.48

Table 9. Parameter estimates from selected models for Tahkenitch Lake coho salmon.

Parameters	Point est.	SE	p value	Lower 90% CI	Upper 90% CI
Model 1: Total recruits, weighted regression, full dataset (37 broods)					
Model performance: $r^2 = 0.371$		Adjusted $r^2 = 0.334$		$p = 0.0004$	
ln(α)	2.060	0.197	<0.001	1.727	2.393
β	0.000870	0.000213	<0.001	0.000510	0.001230
γ	0.132	0.0695	0.066	0.015	0.249
S_{msy}	786				
U_{msy}	0.684				
S_{msp}	1149				
U_{msp}	0.566				
Model 2: Total recruits, general regression, full dataset (37 broods)					
Model performance: $r^2 = 0.451$		Adjusted $r^2 = 0.419$		$p < 0.0001$	
ln(α)	2.190	0.221	<0.001	1.816	2.563
β	0.000965	0.000227	<0.001	0.000582	0.001349
γ	0.173	0.073	0.024	0.049	0.296
S_{msy}	739				
U_{msy}	0.714				
S_{msp}	1036				
U_{msp}	0.619				
Model 3: Adult recruits only, general regression, full dataset					
Model performance: $r^2 = 0.450$		Adjusted $r^2 = 0.418$		$p < 0.0001$	
ln(α)	1.996	0.243	<0.001	1.586	2.406
β	0.000985	0.00025	<0.001	0.000563	0.001407
γ	0.222	0.08	0.009	0.087	0.357
S_{msy}	732				
U_{msy}	0.721				
S_{msp}	1015				
U_{msp}	0.631				
Simulation: Total recruits, general regression, full dataset					
ln(α)	2.172	0.309		1.387	2.385
β	0.000782	0.000207		0.000449	0.001136
γ	0.101	0.07		-0.004	0.224
S_{msy}	960	231		678	1431
U_{msy}	0.707	0.052		0.616	0.784
S_{msp}	1382	423		879	2217
U_{msp}	0.602	0.092		0.436	0.732

Table 10. Escapements of coho salmon and its standard error (*SE*) and coefficient of variance (*cv*) in Tenmile Lakes, 1960-1999.

	Adults			Jacks		
Run year	$N_{a,y}$	$SE[N_{a,y}]$	$cv[N_{a,y}]$	$N_{j,y}$	$SE[N_{j,y}]$	$cv[N_{j,y}]$
1960	5,698	1,531	26.9%	26,967	8,792	32.6%
1961	17,538	4,184	23.9%	20,402	7,014	34.4%
1962	19,992	5,831	29.2%	23,811	8,125	34.1%
1963	11,618	3,251	28.0%	35,426	11,157	31.5%
1964	18,808	4,414	23.5%	28,911	9,341	32.3%
1965	11,951	3,214	26.9%	13,888	5,016	36.1%
1966	14,368	3,749	26.1%	16,362	5,174	31.6%
1967	12,568	2,960	23.6%	23,079	7,705	33.4%
1968	7,967	1,970	24.7%	5,505	1,788	32.5%
1969	7,227	1,671	23.1%	22,346	7,023	31.4%
1970	16,465	3,472	21.1%	62,721	20,891	33.3%
1971	28,157	7,131	25.3%	13,004	5,041	38.8%
1972	9,830	2,460	25.0%	5,025	1,845	36.7%
1973	13,912	2,961	21.3%	9,014	2,881	32.0%
1974	4,415	1,178	26.7%	3,030	1,015	33.5%
1975	2,491	648	26.0%	3,560	1,445	40.6%
1976	1,783	882	49.5%	1,517	5,494	362.3%
1977	2,569	996	38.8%	2,250	5,519	245.3%
1978	1,279	867	67.8%	1,112	5,497	494.2%
1979	978	868	88.8%	1,314	5,496	418.1%
1980	2,775	1,128	40.7%	3,539	5,598	158.2%
1981	3,236	858	26.5%	3,078	2,459	79.9%
1982	2,861	818	28.6%	4,419	1,634	37.0%
1983	777	212	27.3%	732	294	40.2%
1984	4,119	1,551	37.7%	1,717	726	42.3%
1985	3,959	1,189	30.0%	2,929	1,084	37.0%
1986	4,736	1,574	33.2%	2,778	1,108	39.9%
1987	2,060	686	33.3%	1,288	503	39.1%
1988	2,800	883	31.5%	1,869	694	37.2%
1989	2,269	751	33.1%	2,752	1,017	37.0%
1990	1,788	494	27.6%	960	417	43.4%
1991	3,330	886	26.6%	1,010	348	34.4%
1992	2,004	924	46.1%	2,124	5,523	260.1%
1993	5,834	1,738	29.8%	2,872	1,800	62.7%
1994	3,867	1,236	32.0%	3,481	1,813	52.1%
1995	5,741	1,536	26.8%	5,258	2,220	42.2%
1996	7,581	2,021	26.7%	5,922	2,362	39.9%
1997	4,622	1,308	28.3%	4,808	2,152	44.8%
1998	5,504	1,585	28.8%	6,491	2,398	36.9%
1999	6,396	1,752	27.4%	3,673	1,960	53.3%
Mean	7,147	1,934	31.7%	9,523	4,059	82.1%
SD	6,304	1,501	12.6%	12,588	3,967	112.1%

Table 11. Coho salmon freshwater harvests and terminal runs in Tenmile Lakes basin, 1960-1999.

Run	Adult catch		Jack catch		Adult terminal run		Jack terminal run		Harvest rate	
year	$C_{a,y}$	$SE[C_{a,y}]$	$C_{j,y}$	$SE[C_{j,y}]$	$T_{a,y}$	$SE[T_{a,y}]$	$T_{j,y}$	$SE[T_{j,y}]$	$h_{f,y}$	$SE[h_{f,y}]$
1960	238	16	1,127	367	5,936	1,531	28,094	8,799	0.04	0.01
1961	462	30	537	185	18,000	4,184	20,939	7,017	0.03	0.01
1962	366	24	435	149	20,358	5,831	24,246	8,127	0.02	0.01
1963	658	44	2,005	631	12,276	3,251	37,431	11,175	0.05	0.01
1964	258	17	397	128	19,066	4,414	29,308	9,342	0.01	0.00
1965	238	15	276	100	12,189	3,214	14,164	5,017	0.02	0.01
1966	638	41	726	230	15,006	3,749	17,088	5,179	0.04	0.01
1967	195	13	358	120	12,763	2,960	23,437	7,706	0.02	0.00
1968	706	47	488	158	8,673	1,971	5,992	1,795	0.08	0.02
1969	254	16	785	247	7,481	1,671	23,132	7,028	0.03	0.01
1970	910	61	3,467	1,155	17,375	3,473	66,188	20,923	0.05	0.01
1971	665	44	307	119	28,822	7,131	13,311	5,043	0.02	0.01
1972	200	15	102	38	10,030	2,460	5,127	1,845	0.02	0.01
1973	228	15	148	47	14,140	2,961	9,162	2,881	0.02	0.00
1974	103	7	71	24	4,518	1,178	3,101	1,015	0.02	0.01
1975	266	19	380	154	2,757	649	3,940	1,453	0.10	0.02
1976	10	1	9	31	1,793	882	1,525	5,495	0.01	0.00
1977	95	6	83	204	2,664	996	2,333	5,522	0.04	0.01
1978	34	2	30	146	1,313	867	1,142	5,499	0.03	0.02
1979	0	0	0	0	978	868	1,314	5,496	0.00	0.00
1980	24	2	31	48	2,799	1,128	3,569	5,598	0.01	0.00
1981	194	14	185	147	3,430	858	3,262	2,463	0.06	0.01
1982	76	5	117	43	2,937	818	4,536	1,635	0.03	0.01
1983	133	9	125	50	910	212	858	299	0.15	0.04
1984	287	19	120	51	4,406	1,551	1,837	728	0.07	0.02
1985	67	5	50	18	4,026	1,189	2,979	1,084	0.02	0.01
1986	102	7	60	24	4,838	1,574	2,837	1,108	0.02	0.01
1987	15	1	9	4	2,075	686	1,297	503	0.01	0.00
1988	90	7	60	22	2,890	883	1,929	695	0.03	0.01
1989	373	27	452	167	2,642	752	3,205	1,031	0.14	0.04
1990	108	7	58	25	1,896	494	1,017	418	0.06	0.02
1991	144	9	44	15	3,474	886	1,054	348	0.04	0.01
1992	50	3	53	138	2,054	924	2,177	5,524	0.02	0.01
1993	8	1	4	2	5,842	1,738	2,875	1,800	0.00	0.00
1994	95	6	86	45	3,962	1,236	3,566	1,813	0.02	0.01
1995					5,741	1,536	5,258	2,220		
1996					7,581	2,021	5,922	2,362		
1997					4,622	1,308	4,808	2,152		
1998					5,504	1,585	6,491	2,398		
1999					6,396	1,752	3,673	1,960		
Mean	237	16	377	144	7,354	1,934	9,853	4,062	0.04	0.01
SD	231	15	668	215	6,459	1,501	13,165	3,971	0.03	0.01

Table 12. Spawners and recruitment of coho salmon in Tenmile Lakes, brood years 1960-1996.

Brood year	Spawner	Adult recruits			Total recruits		
y	S_y	$R_{a,y}$	$SE[R_{a,y}]$	$Ln(R_{a,y}/S_y)$	$R_{t,y}$	$SE[R_{t,y}]$	$Ln(R_{t,y}/S_y)$
1960	5,698	61,968	16,411	2.39	86,447	18,348	2.72
1961	17,538	64,275	14,881	1.30	102,130	18,686	1.76
1962	19,992	42,446	11,191	0.75	72,044	14,637	1.28
1963	11,618	42,103	10,518	1.29	56,408	11,675	1.58
1964	18,808	47,697	11,063	0.93	64,940	12,235	1.24
1965	11,951	38,100	8,656	1.16	61,778	11,642	1.64
1966	14,368	25,210	5,632	0.56	31,267	5,917	0.78
1967	12,568	50,430	10,079	1.39	73,791	12,327	1.77
1968	7,967	165,872	41,039	3.04	232,669	46,153	3.37
1969	7,227	64,649	15,858	2.19	78,115	16,658	2.38
1970	16,465	79,193	16,581	1.57	84,381	16,686	1.63
1971	28,157	27,758	7,238	-0.01	37,026	7,802	0.27
1972	9,830	15,015	3,532	0.42	18,153	3,678	0.61
1973	13,912	17,932	8,827	0.25	21,917	8,948	0.45
1974	4,415	24,087	9,005	1.70	25,631	10,585	1.76
1975	2,491	7,612	5,026	1.12	9,974	7,519	1.39
1976	1,783	4,813	4,272	0.99	5,968	7,014	1.21
1977	2,569	10,503	4,234	1.41	11,833	6,986	1.53
1978	1,279	18,371	4,595	2.66	21,977	7,288	2.84
1979	978	7,733	2,153	2.07	11,033	3,293	2.42
1980	2,775	4,350	1,015	0.45	8,926	1,936	1.17
1981	3,236	6,549	2,305	0.70	7,416	2,325	0.83
1982	2,861	7,118	2,102	0.91	8,963	2,225	1.14
1983	777	7,314	2,380	2.24	10,311	2,618	2.59
1984	4,119	5,200	1,720	0.23	8,051	2,049	0.67
1985	3,959	6,693	2,045	0.53	8,001	2,107	0.70
1986	4,736	5,957	1,694	0.23	7,901	1,833	0.51
1987	2,060	6,154	1,604	1.09	9,383	1,911	1.52
1988	2,800	6,424	1,638	0.83	7,451	1,692	0.98
1989	2,269	4,230	1,903	0.62	5,291	1,935	0.85
1990	1,788	7,170	2,133	1.39	9,363	5,959	1.66
1991	3,330	4,262	1,329	0.25	7,145	2,241	0.76
1992	2,004	6,560	1,755	1.19	10,130	2,525	1.62
1993	5,834	8,281	2,207	0.35	13,548	3,134	0.84
1994	3,867	5,283	1,495	0.31	11,212	2,798	1.06
1995	5,741	5,980	1,722	0.04	10,796	2,759	0.63
1996	7,581	6,929	1,898	-0.09	13,427	3,060	0.57
Mean	7,280	24,871	6,533	1.04	34,184	7,870	1.37
SD	6,540	31,919	7,561	0.78	44,128	8,355	0.74

Table 13. Parameter estimates from selected models for Tenmile Lakes coho salmon.

Parameters	Point est.	SE	p value	Lower 90% CI	Upper 90% CI
Model 1: Total recruits, weighted regression, full dataset (37 broods)					
Model performance: r^2 = 0.270		Adjusted r^2 = 0.227		p = 0.0047	
ln(α)	1.757	0.200	< 0.001	1.419	2.095
β	0.0000401	0.0000177	0.030	0.000010	0.000070
γ	0.334	0.099	0.0018	0.167	0.501
S_{msy}	15126				
U_{msy}	0.552				
S_{msp}	24938				
U_{msp}	0.336				
Model 2: Total recruits, weighted regression, brood years 1974-96 (23 broods)					
Model performance: r^2 = 0.515		Adjusted r^2 = 0.492		p = 0.0001	
ln(α)	1.993	0.205	<0.001	1.647	2.339
β	0.000240	0.000050	<0.001	0.000156	0.000324
S_{msy}	2643				
U_{msy}	0.629				
S_{msp}	4167				
U_{msp}	0.465				
Model 3: Adult recruits only, weighted regression, brood years 1974-96					
Model performance: r^2 = 0.582		Adjusted r^2 = 0.562		p < 0.0001	
ln(α)	1.786	0.215	<0.001	1.423	2.149
β	0.000287	0.000053	<0.001	0.000198	0.000376
S_{msy}	2338				
U_{msy}	0.671				
S_{msp}	3472				
U_{msp}	0.544				
Simulation: Total recruits, brood years 1974-1996					
ln(α)	2.137	0.203		1.813	2.475
β	0.000257	0.000055		0.000171	0.000351
S_{msy}	2705	455		2118	3530
U_{msy}	0.662	0.051		0.573	0.741
S_{msp}	4088	949		2845	5823
U_{msp}	0.527	0.096		0.359	0.669

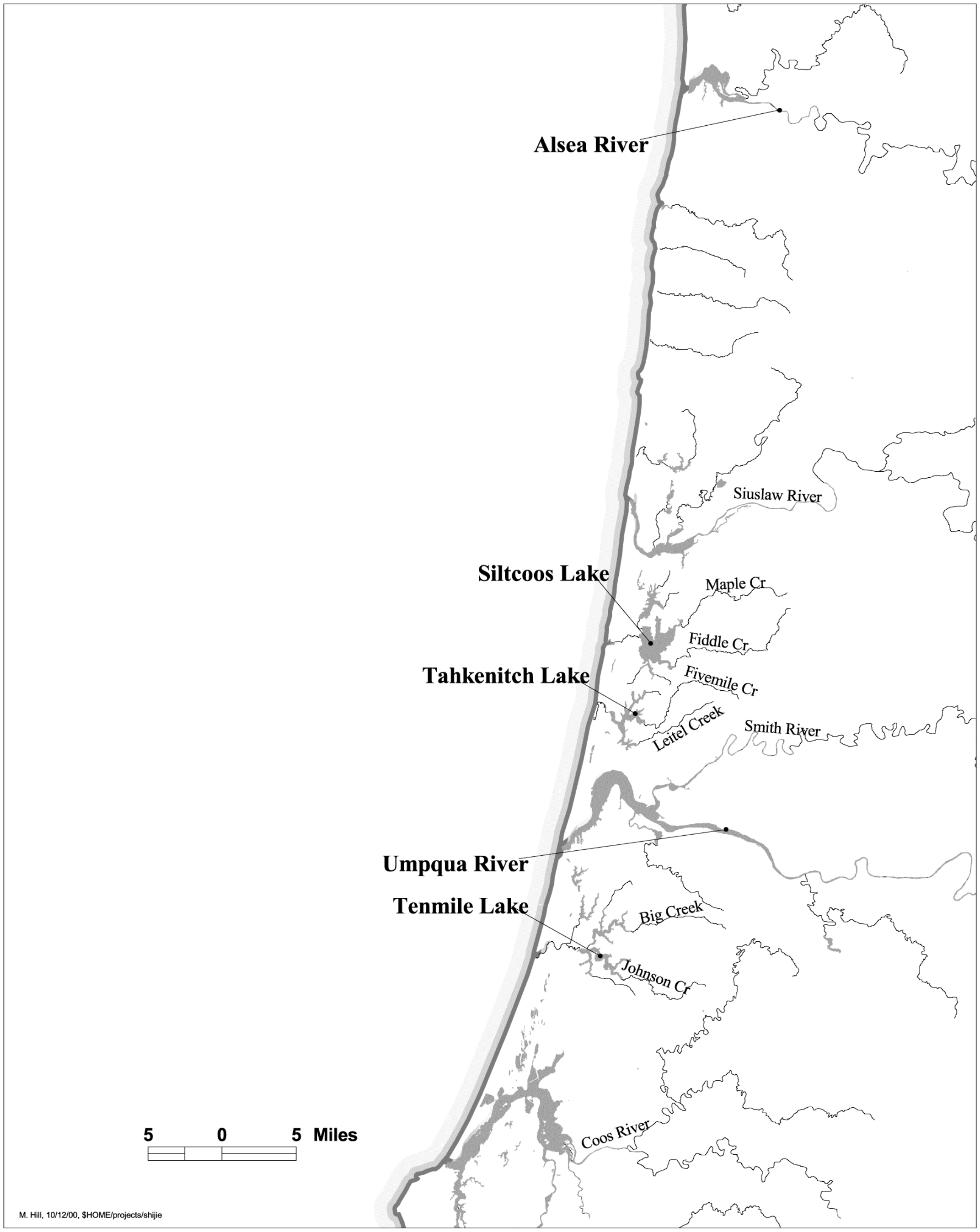

Figure 1. Location of Siltcoos, Tahkenitch, Tenmile lakes and nearby major rivers on Oregon coast.

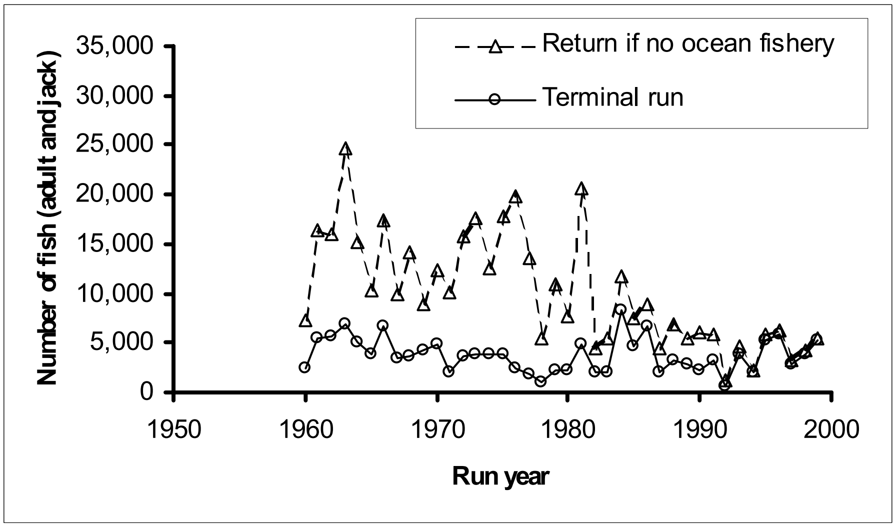

Figure 2. Estimated ocean recruitment and terminal run of coho salmon in Siltcoos Lake basin from 1960 to 1999.

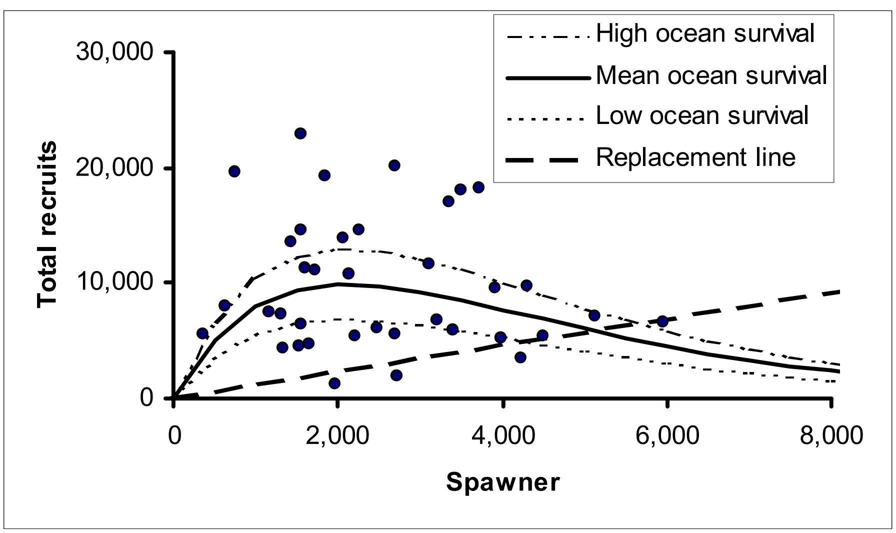

Figure 3. Siltcoos Lake coho salmon spawner and recruitment relationship with regard to high, mean, and low ocean survival rates for Siltcoos Lake coho salmon.

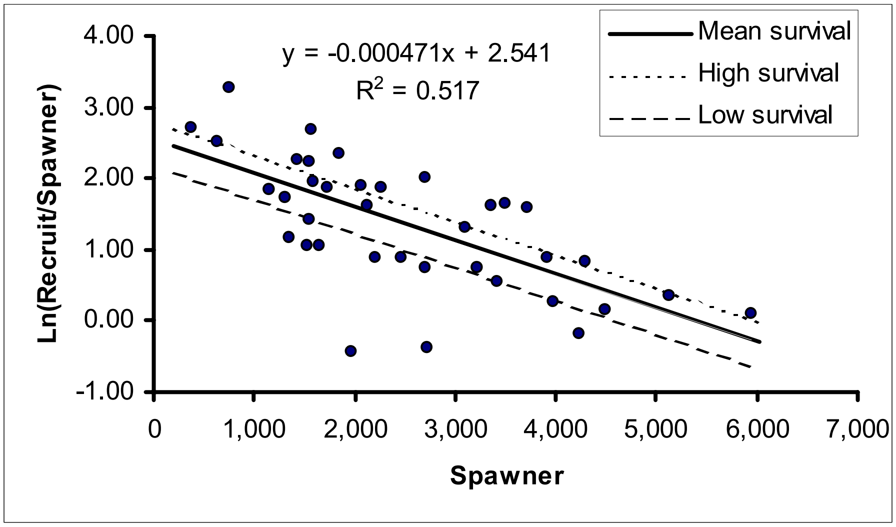

Figure 4. Relationship between ln(R/S) and S with high (3.72%), mean (2.51%), and low (0.89%) ocean survival rates for Siltcoos Lake coho salmon. The equation was for the mean survival rate.

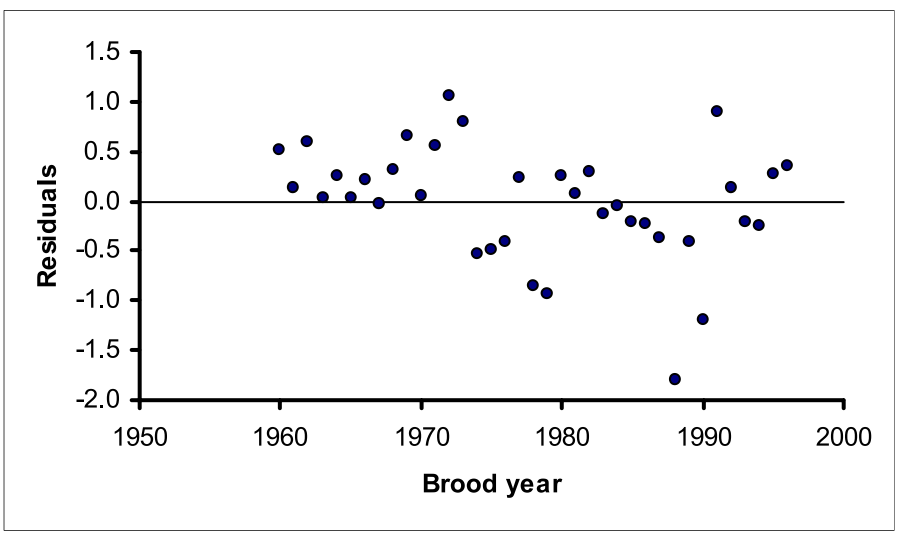

Figure 5. Residuals from stock-recruitment model with weighted regression over brood years for Siltcoos Lake coho salmon.

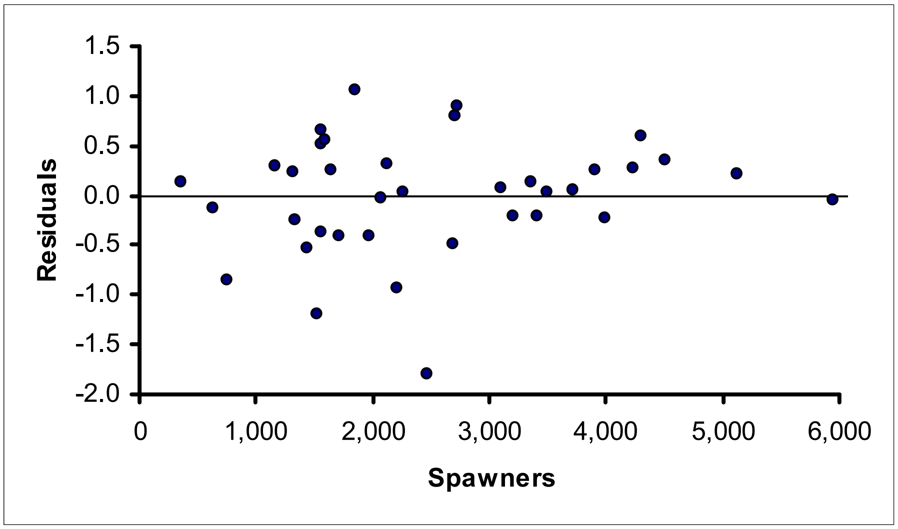

Figure 6. Residuals from stock-recruitment model with weighted regression by spawner abundance for Siltcoos Lake coho salmon.

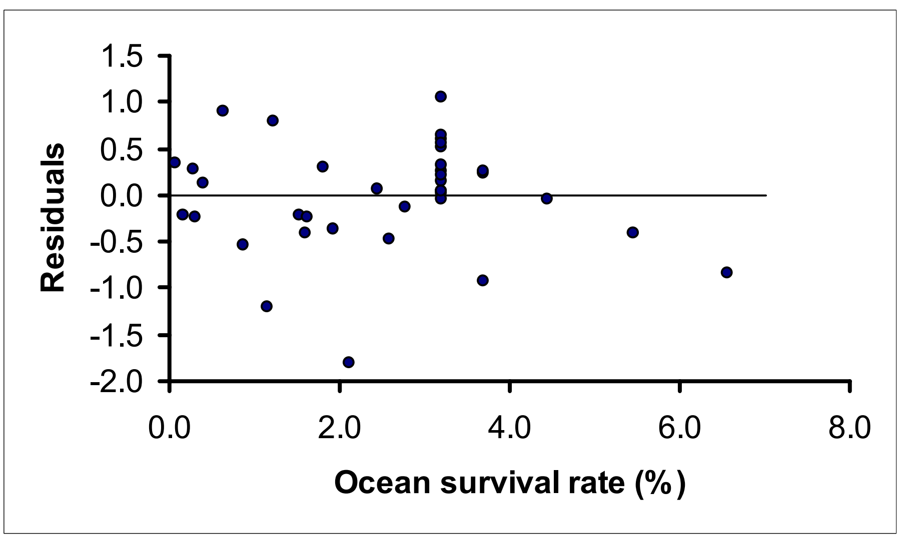

Figure 7. Residuals from stock-recruitment model by ocean survival rates for Siltcoos Lake coho salmon.

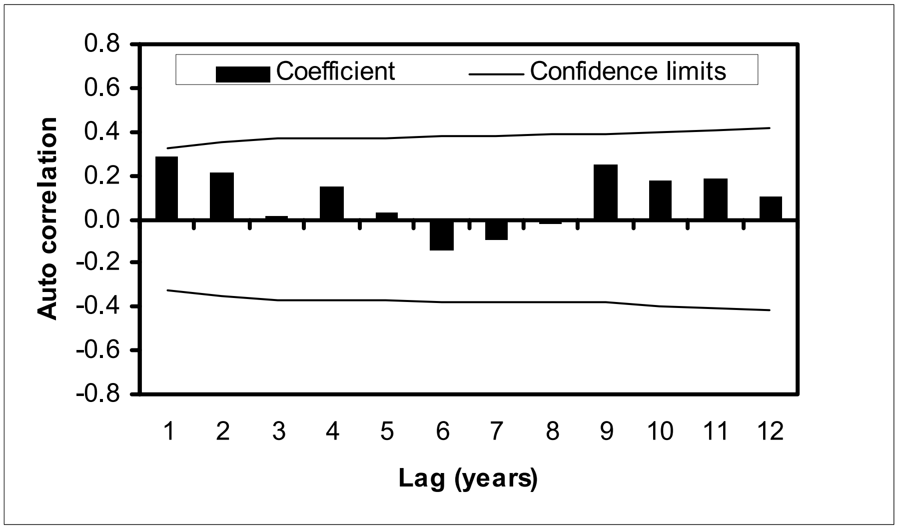

Figure 8. Autocorrelation among residuals from weighted regression for Siltcoos Lake coho salmon.

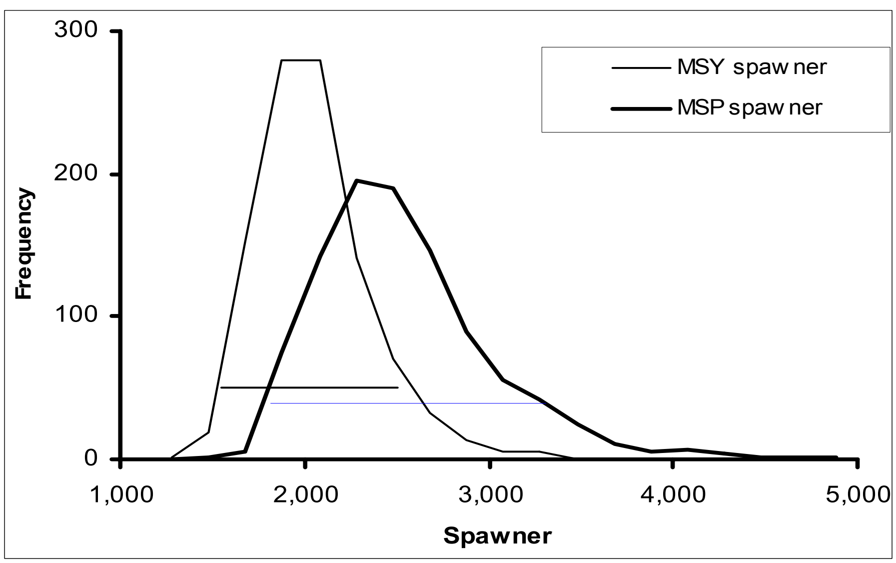

Figure 9. Distribution and 90% confidence intervals for S_{msy} and S_{msp} from Monte Carlo simulations for Siltcoos Lake coho salmon.

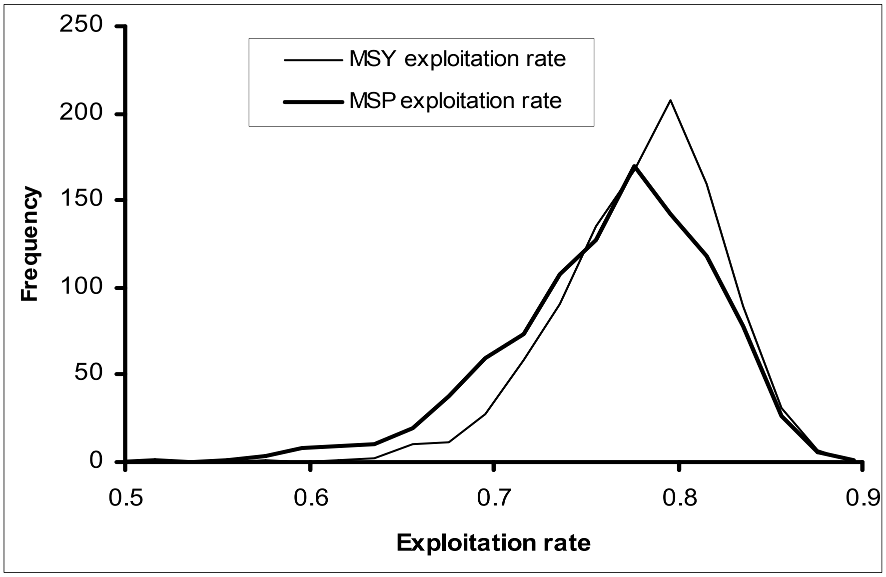

Figure 10. Distribution of U_{msy} and U_{msp} from stochastic simulations for Siltcoos Lake coho salmon.

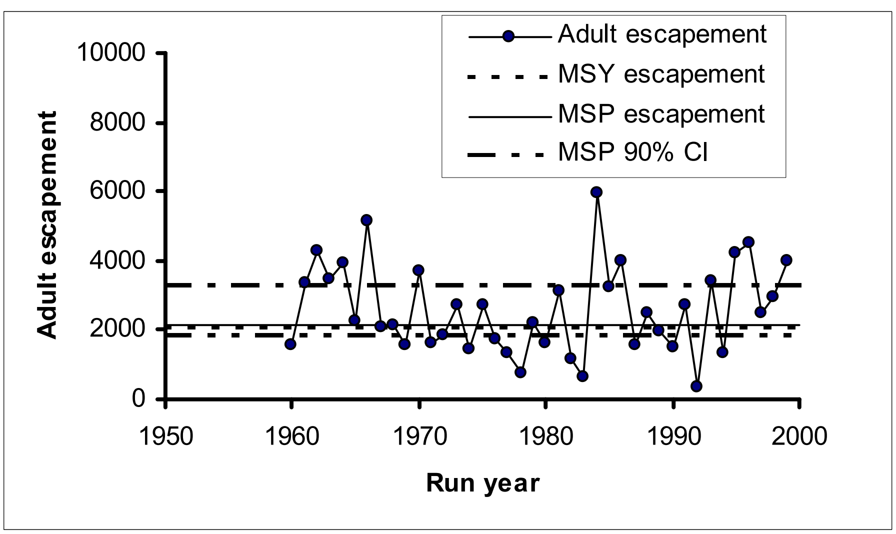

Figure 11. Adult escapements of coho salmon in Siltcoos Lake from 1960 to 1999 with regard to escapement goals.

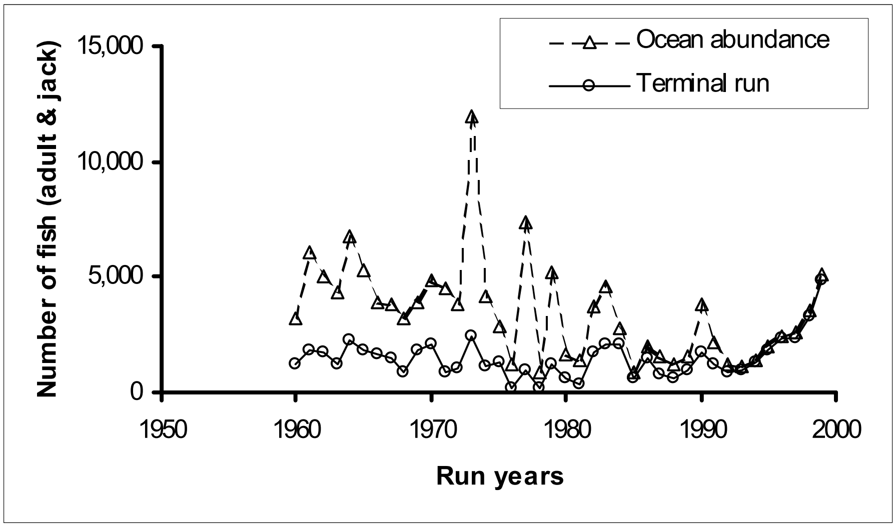

Figure 12. Estimated ocean recruitment and terminal run of coho salmon in Tahkenitch Lake basin from 1960 to 1999.

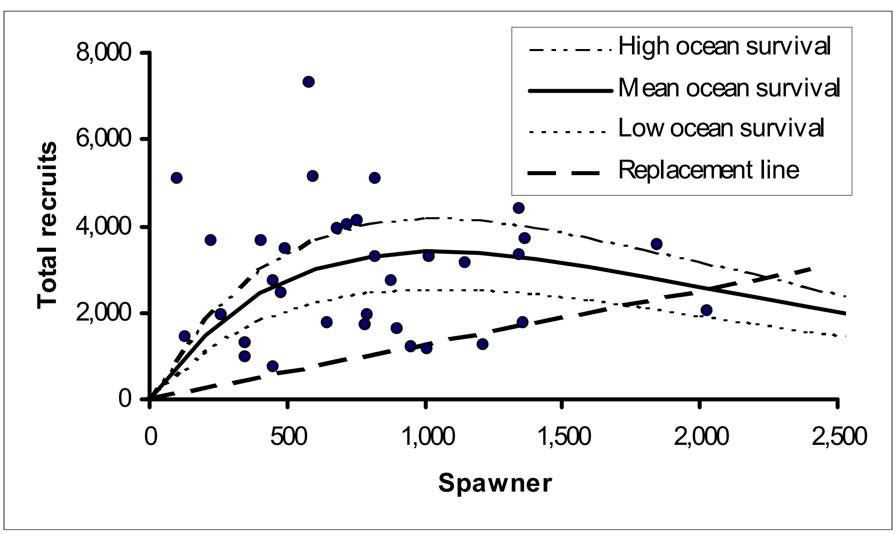

Figure 13. Tahkenitch Lake coho salmon spawner and recruitment relationship with regard to high, mean, and low ocean survival rates.

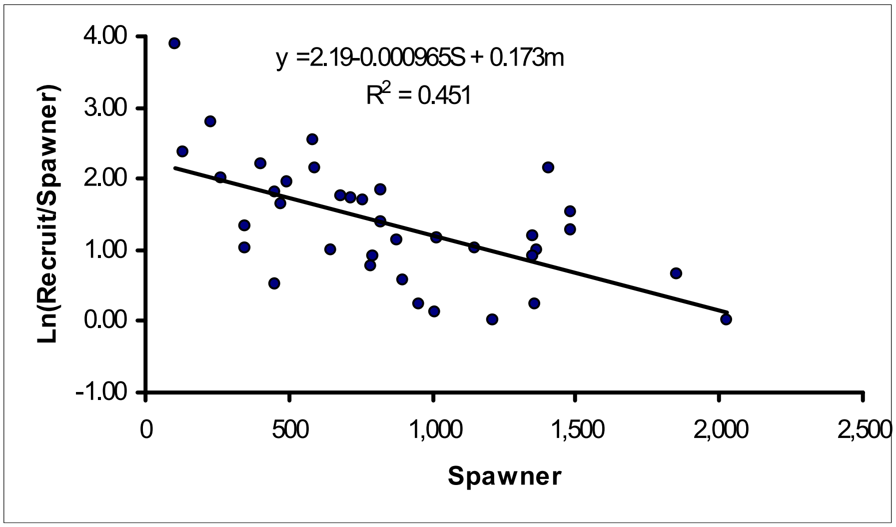

Figure 14. Relationship between ln(R/S) and S under mean (2.51%) ocean survival rates for Tahkenitch Lake coho salmon.

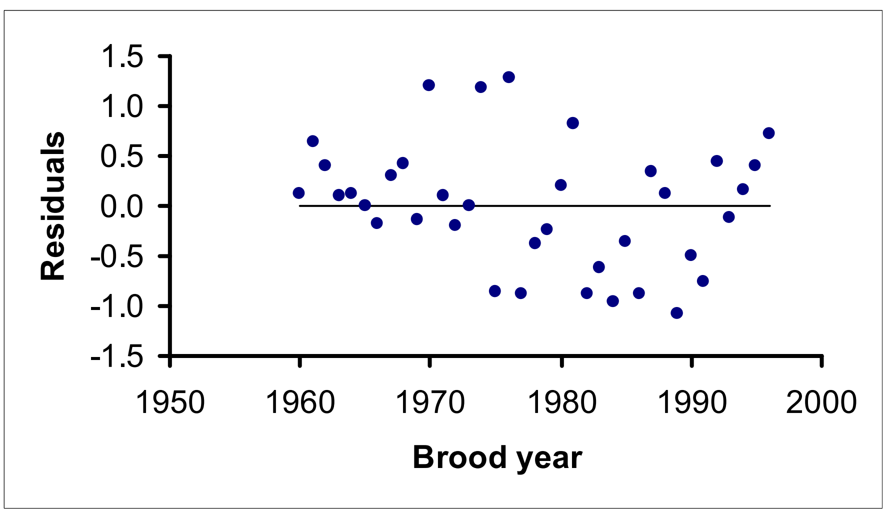

Figure 15. Residuals from stock-recruitment Model 2 (see text) over brood years for Tahkenitch Lake coho salmon.

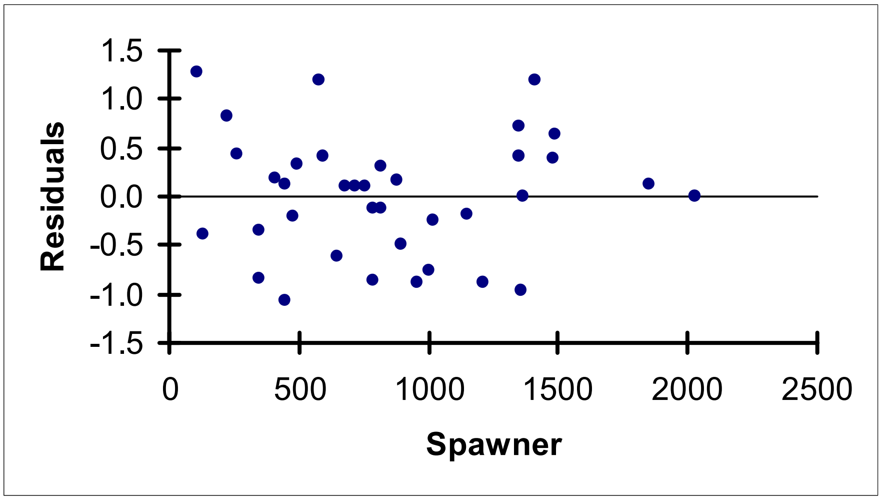

Figure 16. Residuals from stock-recruitment model by spawner abundance for Tahkenitch Lake coho salmon.

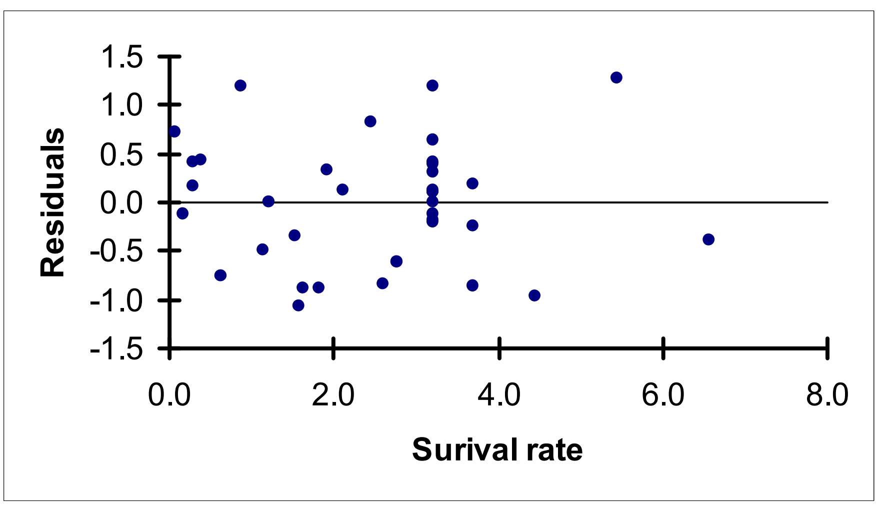

Figure 17. Residuals from stock-recruitment model by ocean survival rates for Tahkenitch Lake coho salmon.

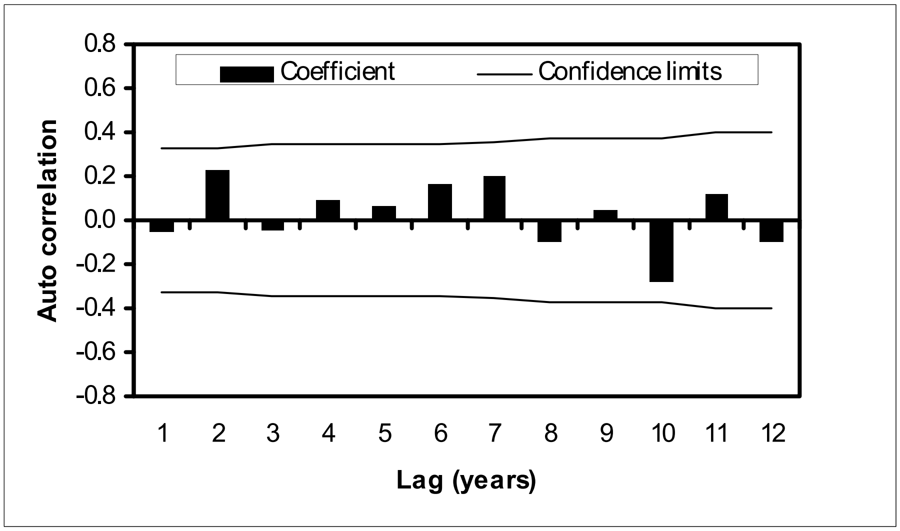

Figure 18. Autocorrelation among residuals from weighted regression for Tahkenitch Lake coho salmon.

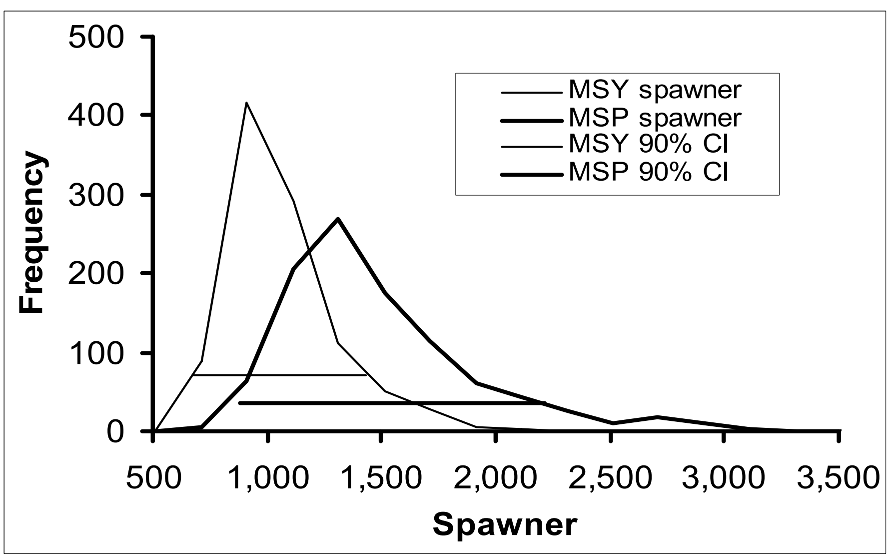

Figure 19. Distribution and 90% confidence intervals for S_{msy} and S_{msp} from Monte Carlo simulations for Tahkenitch Lake coho salmon.

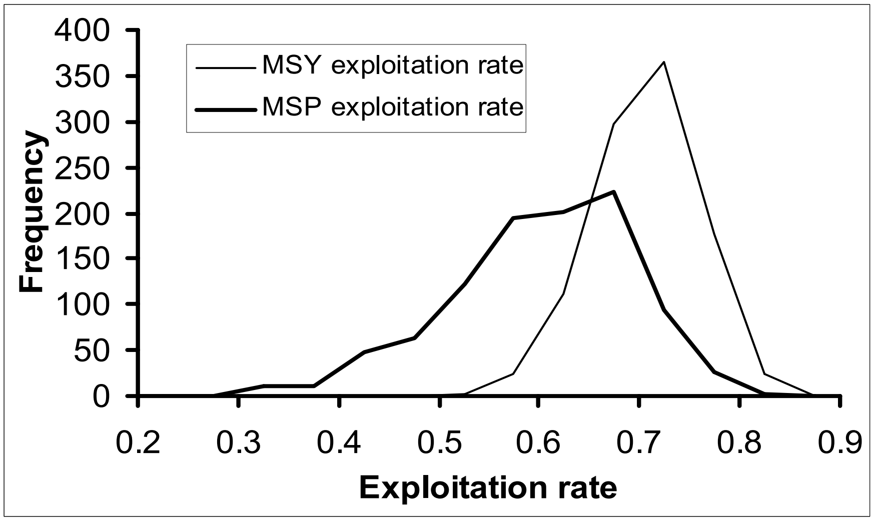

Figure 20. Distribution of U_{msy} and U_{msp} from stochastic simulations for Tahkenitch Lake coho salmon.

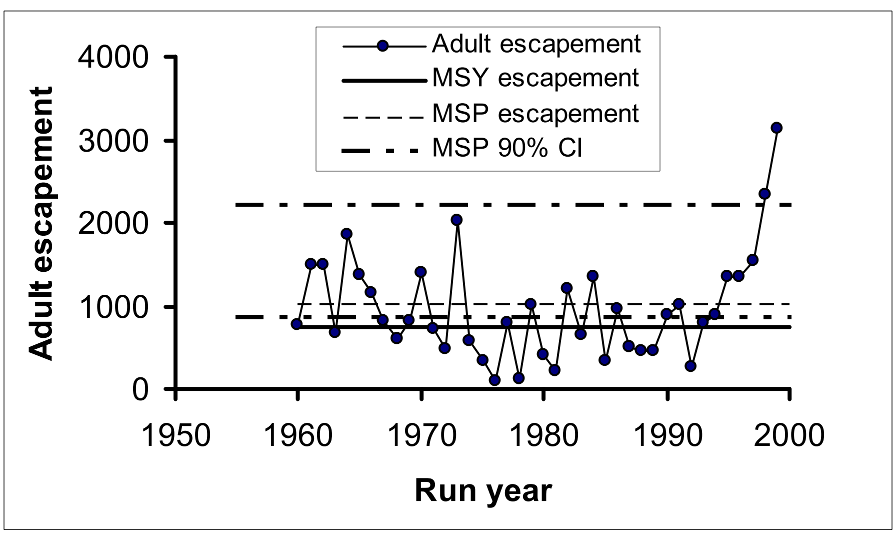

Figure 21. Adult escapement of coho salmon in Tahkenitch Lake from 1960 to 1999 with regard to escapement goals.

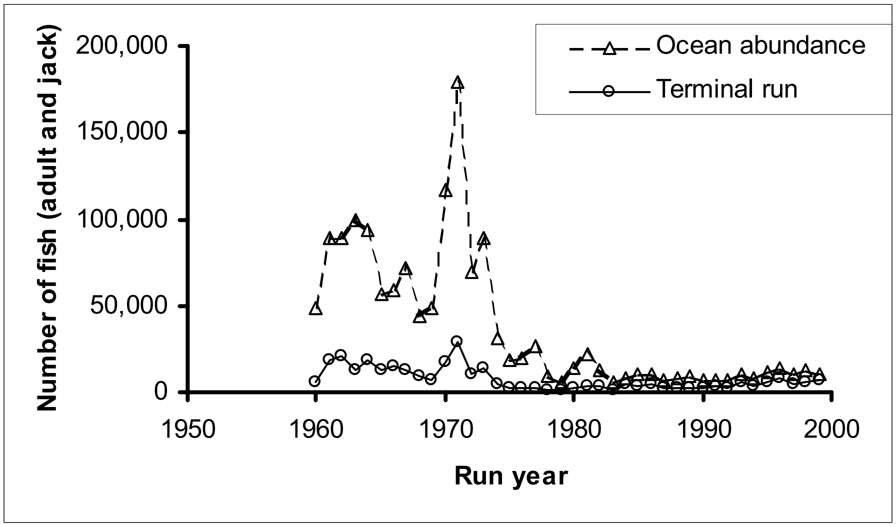

Figure 22. Estimated ocean recruitment and terminal run of coho salmon in Tenmile Lakes basin from 1960 to 1999.

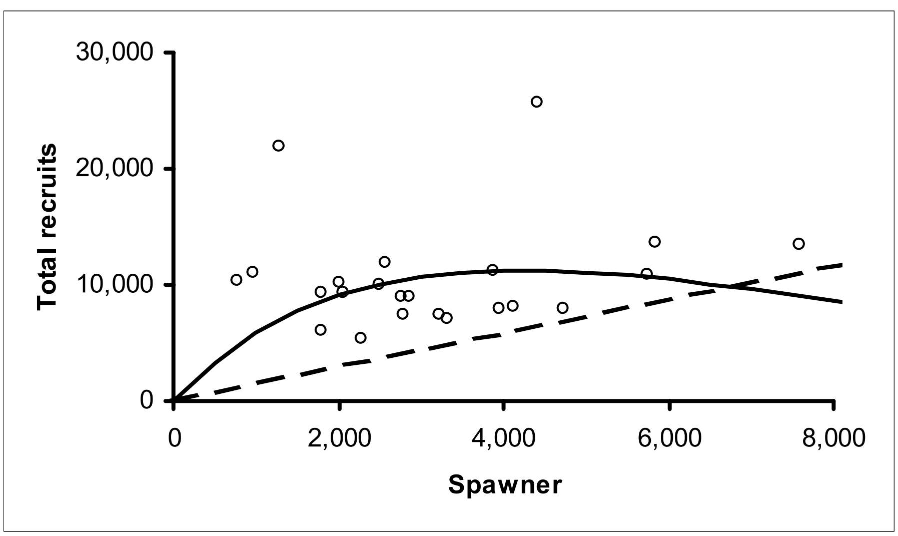

Figure 23. Tenmile Lakes coho salmon spawner and recruitment.

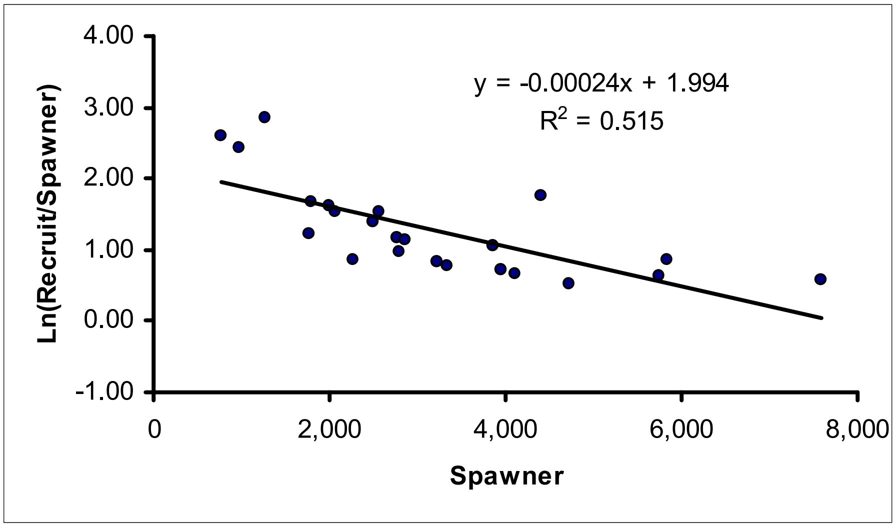

Figure 24. Relationship between ln(R/S) and S for Tenmile Lakes coho salmon.

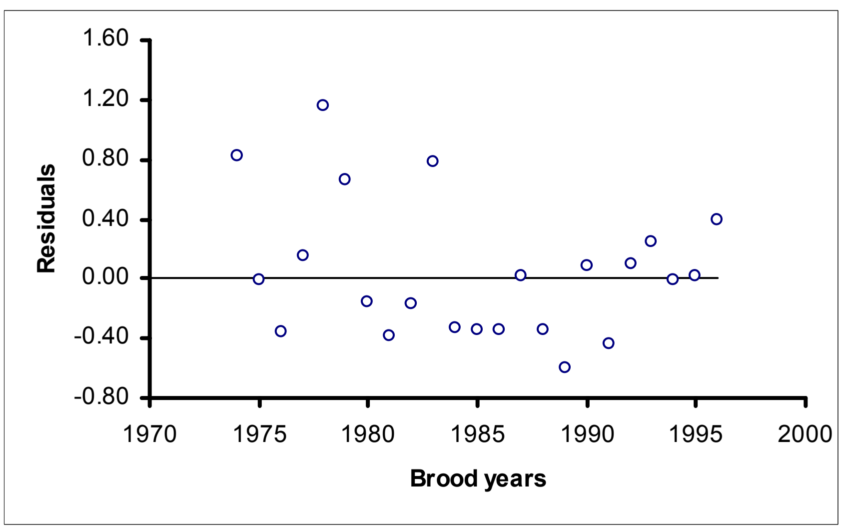

Figure 25. Residuals from stock-recruitment over brood years for Tenmile Lakes coho salmon.

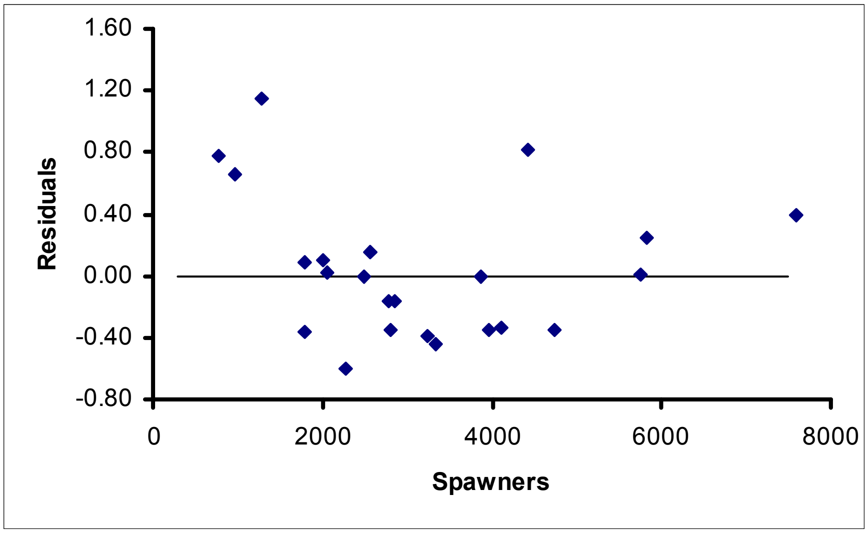

Figure 26. Residuals from stock-recruitment model by spawner abundance for Tenmile Lakes coho salmon.

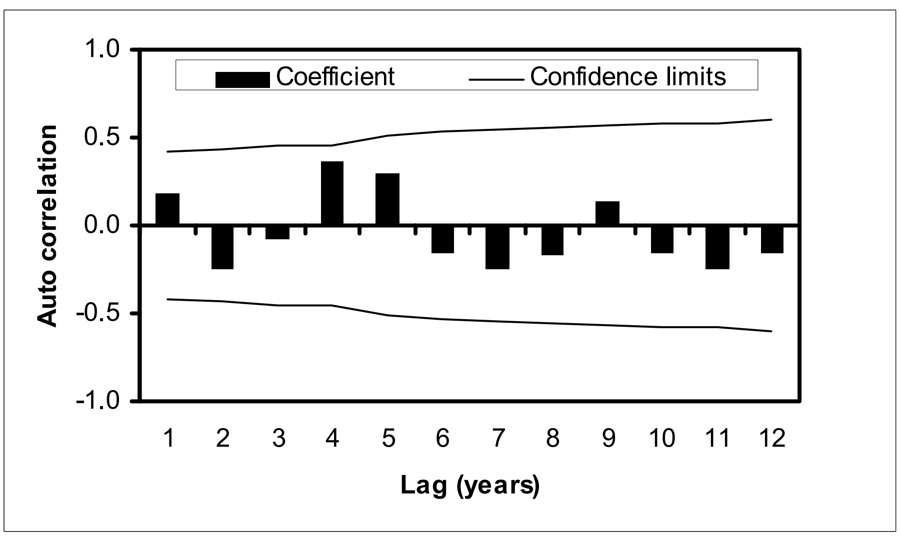

Figure 27. Autocorrelation among residuals from weighted regression for Tenmile Lakes coho salmon.

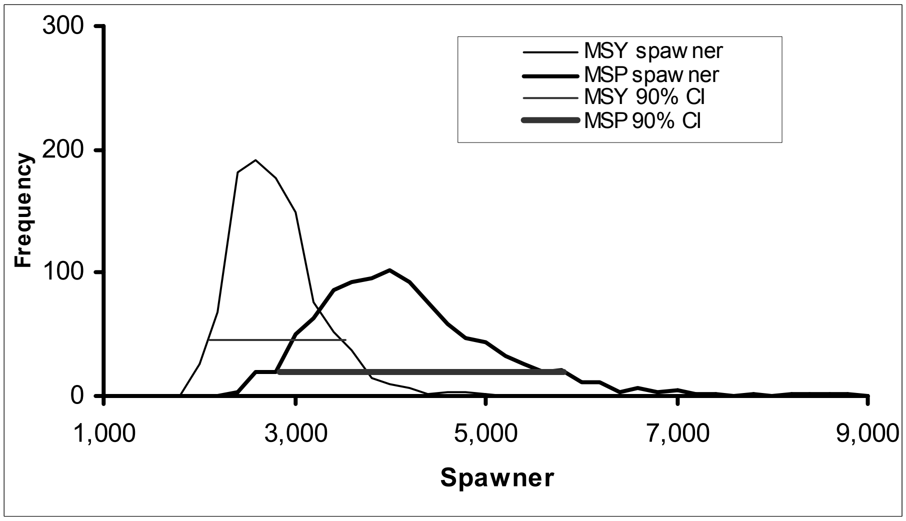

Figure 28. Distribution and 90% confidence intervals for S_{msy} and S_{msp} from Monte Carlo simulations for Tahkenitch Lake coho salmon.

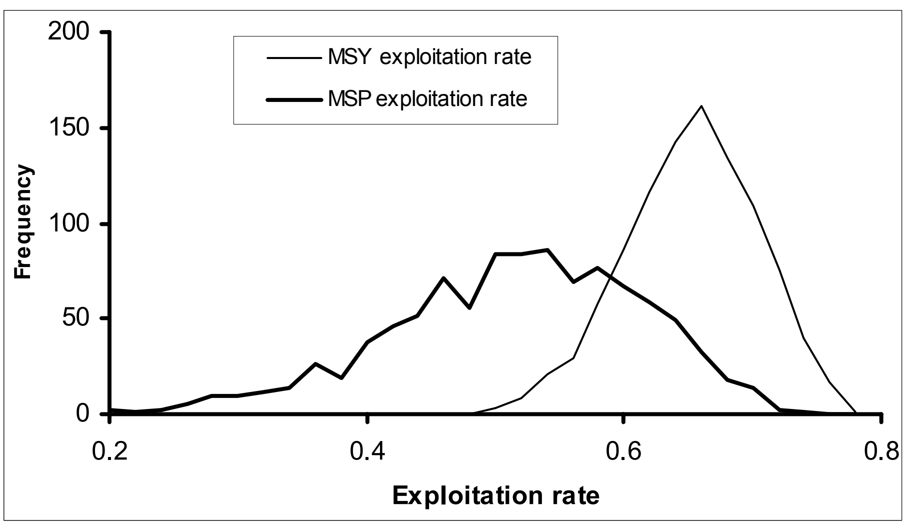

Figure 29. Distribution of U_{msy} and U_{msp} from stochastic simulations for Tenmile Lakes coho salmon.

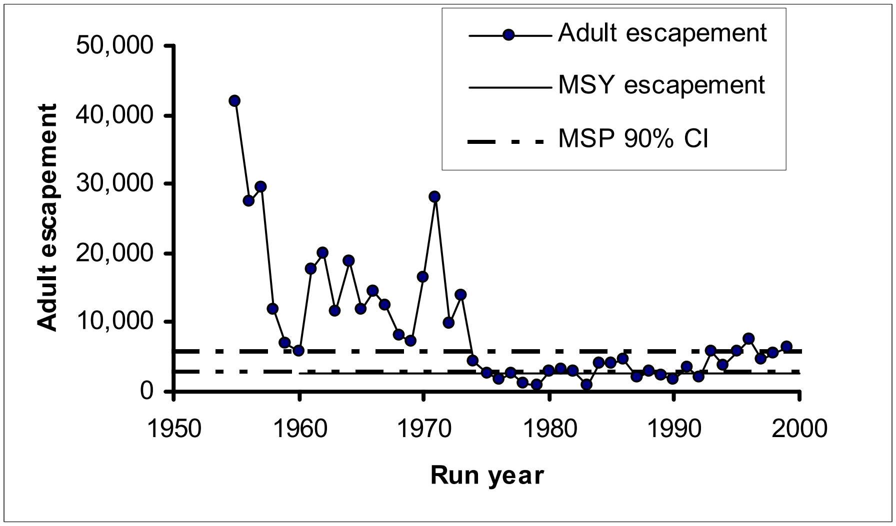

Figure 30. Adult escapement of coho salmon in Tenmile Lakes from 1960 to 1999 with regard to escapement goals.