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Research Document 2005/095

Document de recherche 2005/095

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A Biologically-based Escapement Goal for Cowichan River Fall Chinook Salmon (*Oncorhynchus tshawytscha*)

Objectif biologique d'échappées pour le saumon quinnat *(Oncorhynchus tshawytscha)* d'automne de la rivière Cowichan

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ISSN 1499-3848 (Printed / Imprimé)

Canada

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ABSTRACT

This assessment incorporates spawner recruit data available to 2004 and provides a revised biologically-based escapement goal for Cowichan River fall Chinook, a naturally-spawning population in the lower Strait of Georgia.

Based on the Ricker stock recruit model, excluding the 1981-1984 and 1986-1987 brood years, with the survival rate to age 2 as a covariate (log transformed) the biologically-based escapement goal for adult fall Chinook in the Cowichan River was estimated to be 6,514 (90% CI = 4159, 14962). The associated maximum sustainable exploitation rate at S_{msy} was estimated to be 0.69 (90% CI = 0.52, 0.80).

We recommend that a management plan be established to investigate production potential from escapements exceeding this point and to explore the effect of enhancement on wild stock productivity.

This assessment indicates that productivity and marine survival of the naturally-spawning population has continued to decline while the proportion of hatchery fish in the natural spawning population has increased substantially. At the same time ocean fishery exploitation rates have increased to 70%. Present population sizes are an immediate conservation concern. In 2004, natural escapement was 2226 adult Chinook (2721 total escapement), a similar level only experienced during 1986 -1987 (previous conservation concerns) when survival rates were three to eight times higher.

RÉSUMÉ

La présente évaluation intègre les données disponibles jusqu'à 2004 sur les recrues reproductrices et présente un objectif biologique révisé d'échappées pour le saumon quinnat d'automne de la rivière Cowichan, une population qui se reproduit naturellement dans la portion inférieure du détroit de Georgia.

D'après le modèle stock-recrues de Ricker, en excluant les générations de 1981 à 1984 et de 1986 à 1987 et en utilisant le taux de survie à 2 ans en tant que covariante (après transformation logarithmique), l'objectif biologique d'échappées pour les saumons quinnats d'automne adultes dans la rivière Cowichan a été estimé à 6,514 (90 % IC = 4159; 14962). À S_{msy}, on a estimé que le taux maximal d'exploitation durable connexe était de 0,69 (90 % IC = 0,52; 0,80).

Nous recommandons l'établissement d'un plan de gestion en vue d'étudier le potentiel de production des échappées excédant ce point et d'explorer l'effet de la mise en valeur sur la productivité du stock sauvage.

La présente évaluation indique que la productivité et la survie en mer de la population qui se reproduit naturellement a continué de diminuer, même si la proportion de poissons d'écloserie dans cette population a sensiblement augmenté. Parallèlement, le taux d'exploitation des pêches en mer a grimpé à 70 %. La taille actuelle des populations constitue un souci immédiat pour la conservation. En 2004, les échappées naturelles étaient de 2226 saumons quinnats adultes (l'échappée totale était de 2721); des niveaux semblables n'ont été atteints qu'en 1986-1987 (où la conservation était préoccupante), alors que les taux de survie étaient de trois à huit fois plus élevés.

INTRODUCTION

In 1985, a program to increase Chinook production was initiated coastwide through the Pacific Salmon Treaty between the United States and Canada. The program required both countries to stop the decline in escapements to naturally-spawning Chinook stocks and attain escapement goals in selected indicator stocks by 1998 (PSC 1987). To achieve these objectives the Treaty established catch limits in mixed-stock Chinook fisheries, and required that the catch of Chinook in other fisheries be limited by harvest rate controls so that most of the savings from ocean fisheries could be passed through to the spawning grounds. However, to implement this program, escapement goals to restore production were needed for the Canadian Chinook stocks. These were generally not available during the early 1980s and the status of Chinook stocks was uncertain (Healey 1982). Generally, Chinook production was considered to be depressed from past years but the status of individual populations had not been determined. In order to proceed with the Treaty intent to restore Chinook production, Fisheries and Oceans staff were directed to establish interim escapement goals for Canadian Chinook stocks. The recommendation of a Regional workshop in 1982 was to double the spawning escapements observed during a recent period (1979-1982 chosen) and to monitor escapements during the rebuilding period in order to allow determination of biologically-based goals.

The Cowichan River fall Chinook was selected as an indicator stock for Chinook salmon produced naturally in the lower Strait of Georgia. However, by the fall of 1987, spawning escapement to the Cowichan River had decreased to only 15% of its escapement goal. In response to the continued decline in escapement, further conservation measures were taken to reduce harvest rates and enhancement guidelines were implemented to assist recovery (Riddell and Kronlund 1993). Further, an intensive program of escapement enumeration and assessment was established (Nagtegaal et al. 1994a).

The Cowichan River

The Cowichan River flows into Cowichan Bay on the east coast of Vancouver Island, British Columbia, approximately 40 km north of Victoria. The river flows from Cowichan Lake eastward for 50 km into Cowichan Bay. Skutz Falls, 18 km downstream from Cowichan Lake, presented a partial obstruction to salmon migration which was alleviated by fishways constructed in 1956. The Cowichan drainage area is 840 km^2 and carries a mean annual discharge of 55 m^3/sec. Mean monthly discharges range from 117 m^3/sec in December to 8.3 m^3/sec in August. A low-level flow control dam at the outlet of Cowichan Lake, built in 1957, provides a minimum river discharge of 7 m^3/sec. A fishway in the dam permits fish passage to Cowichan Lake. The Cowichan River system supports Chinook, coho and chum salmon populations. Chinook salmon spawn in the main Cowichan River, principally upstream of Skutz Falls.

Interim Escapement Goals

The 1982 interim escapement goal for the Cowichan River was set at 11,625 adult Chinook (ie. Age 3 and older Chinook). In some past documents the escapement goal for the Cowichan River was stated as 12,500 adult Chinook. This value included escapements recorded in the Koksilah River adjacent to the Cowichan, but that population should not be included in the Cowichan River Chinook goal.

According to the revised 1999 international agreement, additional management actions for a Chinook stock of conservation concern can only be considered when a biologically based escapement goal has been developed and approved by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC). In 2000, Riddell et al. compiled the information available on the status of the Cowichan Chinook stock, recommended a set of historical escapement values to apply in assessments, and provided the first assessment of a biologically-based escapement goal for naturally-spawning Chinook in the Cowichan River. They recommended an interim escapement goal of 7,400 (95% confidence intervals: 4,185-18,915). Although this interim goal was accepted by PSARC (May 2000), the subcommittee recommended that an escapement policy be developed that allowed escapements in excess of the goal to further evaluate production potential for the stock and that exploitation rates on the stock should not be increased until productivity rates are known to be increasing. In 2004 a revised goal was proposed but not accepted by PSARC. The PSARC requested a new analysis to decouple the density dependent ocean survival effects from potential hatchery effects (Appendix 1).

Objectives

In this assessment our objectives were to:

- Review and verify historic escapement data,
- Compile additional escapement data available (since 2000) and incorporate in the stock recruitment analysis,
- Investigate the use of juvenile production data to decouple density dependent ocean survival effects from hatchery effects, and
- Provide a revised estimate of a biologically-based escapement goal for naturally-spawning fall Chinook in the Cowichan River.

Enhancement of Cowichan River Chinook

A community economic development program hatchery (CEDP) has been established on the Cowichan River approximately 2 km upstream from Cowichan estuary. The hatchery is managed by the Habitat Enhancement Branch of DFO in conjunction with Cowichan Tribes. Hatchery production of Chinook on the Cowichan River began in 1980 (Cross et. al., 1991). In most years, a proportion of the Chinook produced are nose-tagged with a small coded-wire tag (CWT) for assessment of hatchery production. Recovery information from these tags provides the basis for assessing exploitation rates, distribution, and marine survival for these stocks. Since no naturally-spawning Chinook are tagged, information compiled from the hatchery facility is used to assess both hatchery and naturally-spawning Chinook.

Enhanced production of Cowichan Chinook has increased considerably since the hatchery was established in 1979 (Fig. 1), largely owing to significant expansion of the hatchery facility following the agreement on a conservation plan for lower Strait of Georgia Chinook. Poor escapements observed during 1986 and 1987 indicated a conservation concern for this population and a public consultation process was undertaken. The resulting plan included new management actions in fisheries to reduce exploitation and additional enhancement of Cowichan Chinook to increase the productivity of the stock. The plan provided a commitment that Cowichan fall Chinook salmon were to be managed for natural production, with supplementation from the hatchery occurring under two guidelines:

1. enhanced returns were not to exceed 50% of the total adult escapement goal, once the population achieved its goal; and

2. enhanced production was not to increase beyond the 1987 level until escapement exceeded the 1987 escapement level. The 1987 enhancement production would, however, be maintained if the escapement decreased from the 1987 level.

Two qualifiers were placed on the second item. Transplanting of surplus Chinook eggs from other stocks to accelerate the enhanced production in the indicator stocks was not acceptable. Other innovative techniques such as sea pen rearing of smolts could be applied to help accelerate the attainment of egg capacities.

Since 1990, the enhanced contribution to the naturally-spawning population, has averaged 31% but ranged as high as 72% (2002) based on the incidence of coded-wire tagged (adipose fin-clipped) Chinook recovered in the escapement. Another estimate based on otolith microstructure, suggests the proportion of hatchery Chinook in the Cowichan River is greater than that estimated by CWTs, as high as 60% in 1992 and 1993 (Zane Zhang pers com). In either case, it is clear that enhancement contributed to recent annual escapements.

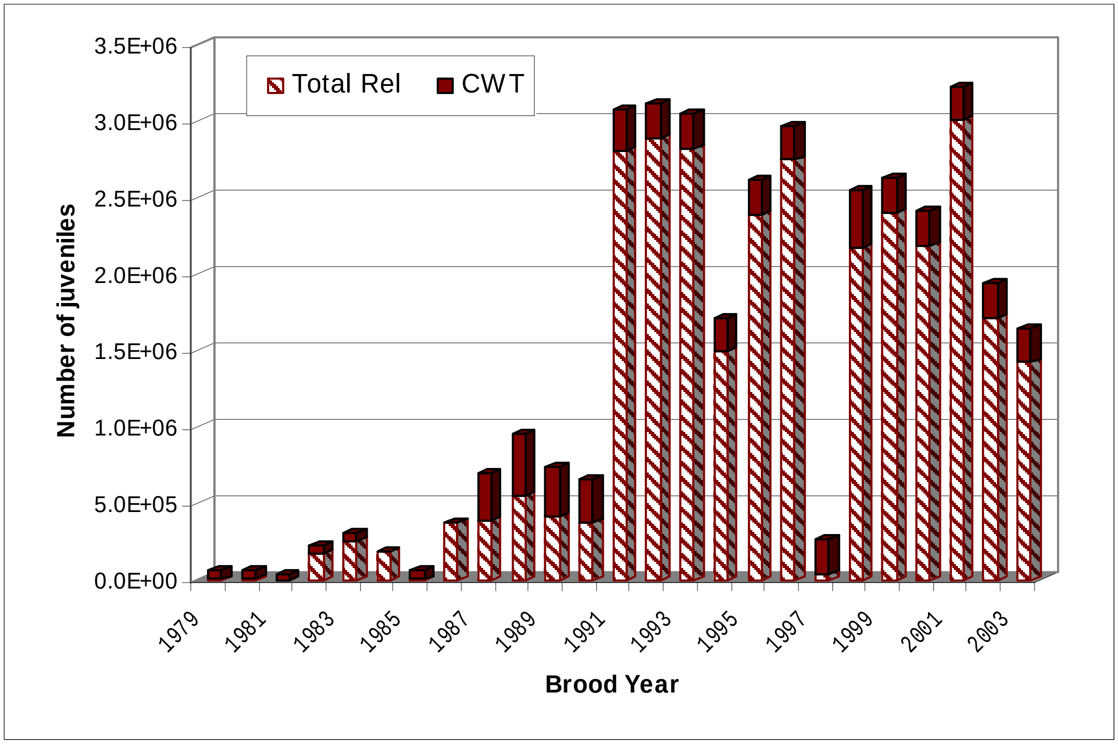


Figure 1. Numbers of Chinook tagged and total releases from the Cowichan CEDP facility since 1979.

Methods

Enumeration of Spawning Escapements

Prior to 1980, escapement was estimated based on stream walks, index sites and anecdotal information from various sources. From 1980 to 1990, fishery officers estimated total escapement in the Cowichan River on the basis of regularly scheduled swim surveys, observation of spawning ground index sites, and aerial counts (helicopter) of spawners during peak spawning periods. Attempts were made to keep the timing and application of these techniques consistent from year to year (see Escapement Summary in Appendix 2).

During swim surveys, only the upper river (Lake Cowichan to an area referred to as "Three Firs" which is approximately 6 km upstream from Skutz Falls) was generally surveyed since few fish had been observed below this area. Counts were usually made by 2-3 swimmers equipped with snorkelling gear accompanied by another person in a canoe or boat. The upper stretch of the river was divided into segments (usually associated with pools) and counts recorded by segment. Total numbers of adult and jack Chinook were discussed by the swimmers at the end of each of these segments before the final tally was recorded by the boat operator. The swim survey count was then extrapolated for the whole river on the basis of the area sampled, date, past observations, discussions with Cowichan Indian Band members, and local knowledge (T. Fields, Fishery Officer, Duncan, pers. comm.).

Early in the season (July-Sept) swim counts were generally multiplied by a factor of approximately 4.8 to get an estimate of the number of fish in the entire river. This expansion factor was based on the proportion of river observed relative to the total length of the river and the assumption that at this time of the season fish were not distributed evenly throughout the river. Towards the end of the season, upper river visual counts were expanded to total escapement using a factor less than 4.8 assuming that by this time most of the fish had moved into the upper section of the river. The quality of the data collected was variable and dependent to a great extent on water conditions (depth and clarity). When the opportunity arose and water conditions were good, a helicopter flight was used to count Chinook on the spawning grounds during peak periods and this count was used to augment the swim survey data.

Since 1990, swim surveys have been conducted in conjunction with Cowichan Tribes Aboriginal Fisheries Management to estimate the spawning population of Chinook (Paige 1992, 1995). The swims continued to be made in the upper section of the river but with less consistency. Counts were recorded by pool/riffle and then compiled by river section. When possible the same swim team was used for each survey to maintain consistency in counting procedures. Swim counts were intended to be expanded by a factor of approximately 3.4 to derive an escapement estimate. This expansion factor was to be consistently applied to all swim counts with no adjustments made for run timing or changes in the distribution of Chinook in the river. Since the late 1990s, swim surveys have not consistently been done, expansion factors inconsistently applied, and spawner index sites have not been referred to. Final DFO escapement estimates have been based primarily on fence counts and expansions based on cumulative run timing to account for periods of high flow when the fence could not be operated.

In 1988, an enumeration fence was constructed at a site approximately 5 km. upstream of the estuary and well below the traditional Chinook spawning grounds (Nagtegaal et al. 1994a). The fence has generally been operational from the end of August until the end of October. All species were counted by personnel that maintain the facility 24 hours per day. In some years, to augment the fence count, a carcass mark-recapture program involving the tagging and subsequent recovery of Chinook jack and adult carcasses has been conducted on the spawning grounds. Adult Chinook salmon escapement estimates were also generated from the carcass mark-recapture data using the Petersen model (Chapman modification) stratified by sex and river section (Sykes and Botsford 1986).

Details of escapement monitoring programs since 1988 are contained in annual reports prepared by Nagtegaal and others (1994a, 1994b, 1994c, 1995a, 1995b, 1996, 1998a, 1998b, 1999). Observed and expanded spawner estimates for each survey method, snorkel surveys, weir counts, and carcass mark-recapture programs, are presented in figure 2 for comparison.

Chinook escapement has fluctuated from lows of 2100 - 2500 Chinook in 1986 and 1987 to over 16,000 in 1995, the largest escapement recorded for the past 20 years (Figure 3, also see Appendix 2 for enumeration results by method).

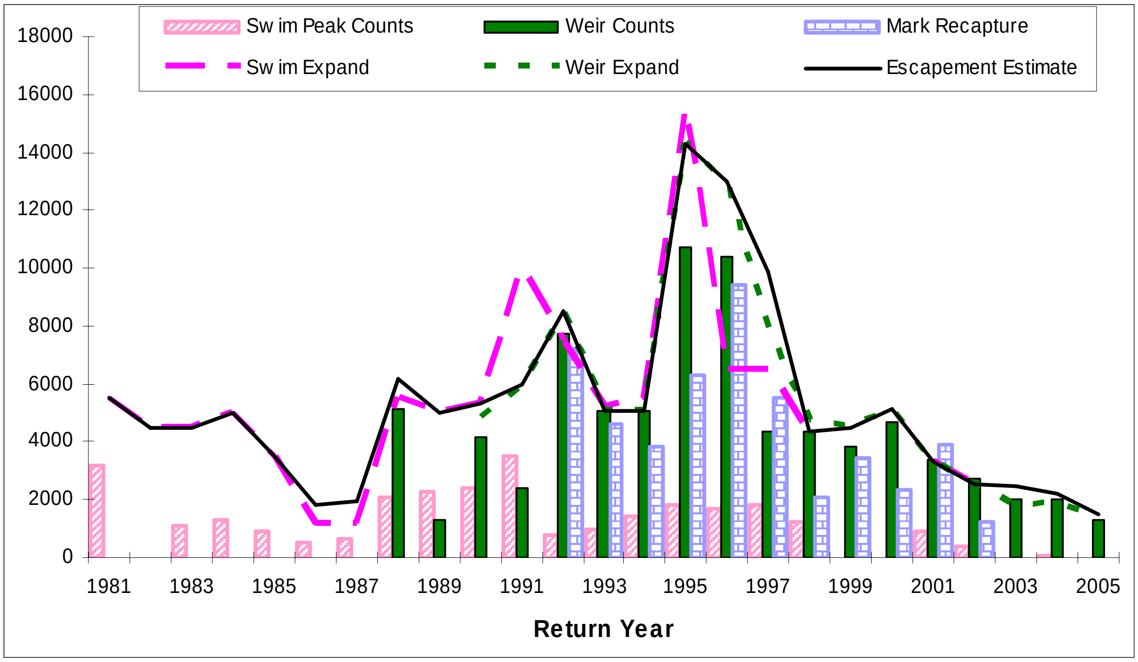


Figure 2. Comparison of observed and expanded spawner estimates from snorkel surveys, weir counts, and the carcass mark-recapture program.

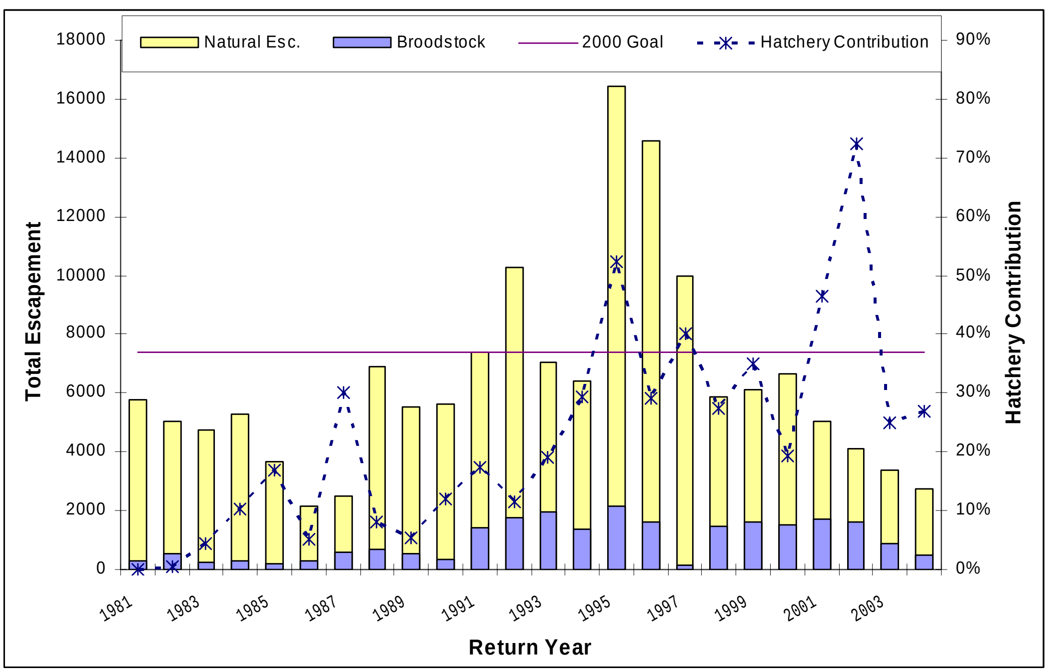


Figure 3. Estimated spawning escapements of the Cowichan River fall Chinook and comparison with interim escapement goal established in 2000 (dashed line). Bar height determined by the sum of the number of natural spawners plus the brood stock removed for use in the hatchery.

To better understand the relative value and accuracy of past Fishery Officer visual escapement estimates, we compared these visual estimates, in particular swim survey counts and extrapolated escapement estimates, to fence counts. Assumptions concerning the distribution of Chinook in the river at the time of the survey are the basis for expanding these counts to estimate total escapement. Fishery Officers adopted a strategy that consistent expansion factors were to be applied to swim survey counts from the upper river, to estimate the total numbers of Chinook spawners. In 1991, it became apparent that during high water flow conditions in early fall, expansions based on swim survey results over-estimated total escapement (Nagtegaal et al. 1994b). The results of the 1992 swim surveys supported the hypothesis that during low water flow conditions in the late fall, expansions based on swim survey results under-estimate the numbers of spawners. Similarly, Lister et al. (1981) reported Cowichan Chinook migration coincided with significant increases in river discharge. The standardized swim survey strategy adopted by Fishery Officers has likely led to annual inaccuracy due to incorrect estimation of spawners because the distribution of fish in the river was affected by the flow (Fig. 4). If we apply this approach to past Fishery Officer visual escapement estimates (see Appendix 2), then the very low estimate of spawners in 1986 and 1987 were likely an under-estimate, and the estimate in 1991 was likely an over-estimate.

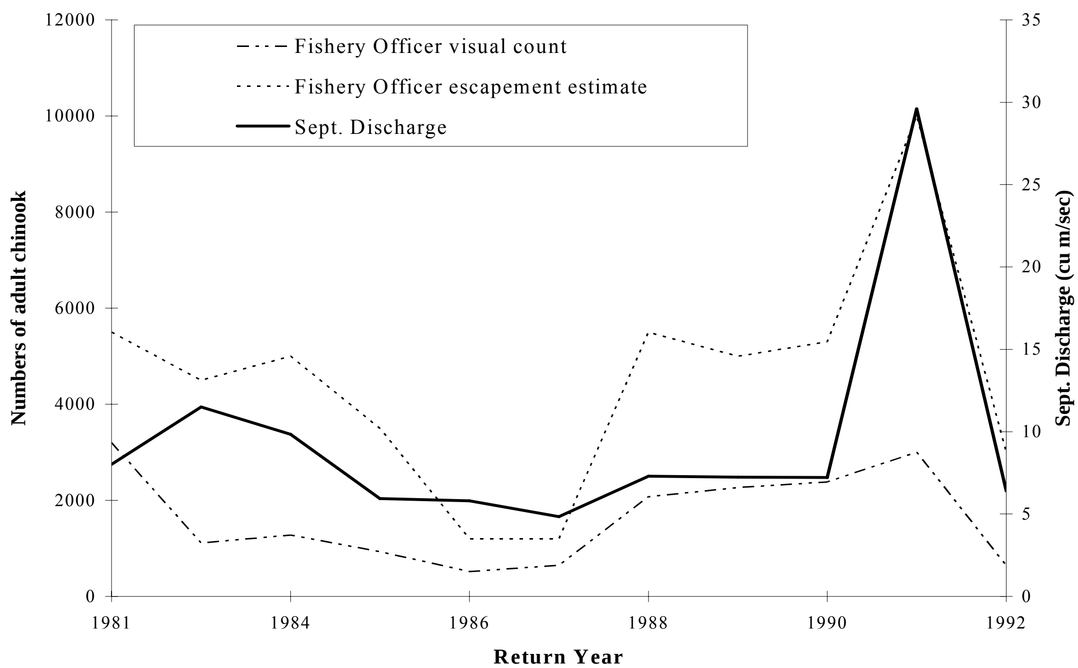


Figure 4. Comparison of Fishery Officer swim survey peak counts, final estimated total spawning escapement and discharge for September in the Cowichan River.

Native Fishery

Although more poorly evaluated, the terminal native fishery has been considered minimal relative to the total catch of Cowichan fall Chinook in ocean fisheries. Chinook are caught for food and ceremonial purposes using a variety of traditional techniques. The Cowichan Tribes Band, comprised of approximately 600 family units, resides on reserve land that encompasses much of the area surrounding the lower reaches of the Cowichan River. The native fishery for Chinook takes place in the form of a spear fishery during the months of June-October.

Prior to 1983, the native food fishery was monitored by the Department. Fishery Officers would estimate total catch on the basis of observations and discussions with local native groups. Since 1983, the Cowichan Tribes established the Cowichan River Management Unit (CRMU) to enforce conservation by-laws on the reserve. The amount of time and resources spent on monitoring the native food fish catch varies from year to year. The River Management Team regularly patrolled the food fishery and collected data to estimate total food fish catch, however their first priority was enforcement. Routine patrols for these activities did not always coincide with the activities of the spear fishermen, who accounted for virtually all the Chinook native food catch.

In 1990, a systematic approach was developed by the Cowichan Tribes Aboriginal Fisheries Management program to monitor the fishery more closely and to better estimate the native food fish catch (Paige 1992, 1995). This approach involved recording catch and effort by management zone within the native fishing boundaries. A crew of four observers patrolled the fishery on a daily basis and interviewed fishermen for numbers caught by area and total time spent fishing. In this way, weekly estimates of catch per unit effort (CPUE) were obtained. CPUE was adjusted for daily changes in fishing effort and differences in effort among fishing zones. These data were then extrapolated over time and area to estimate total catch by week.
Since 1988, an observer was employed intermittently by DFO to independently collect catch and biological data from the in-river Chinook spear fishery. Since we are not given the opportunity to directly assess catch estimation procedures developed by the Cowichan Tribes, no comments can be made regarding the methodologies used. At best these two estimates of native catch provide a range of the actual food fish catch (Nagtegaal et al. 1995).

Seal Predation

Although seal predation was not directly assessed in this study, others have examined the impact of seals on salmon in Cowichan Bay. An estimated 23% (Sept.) to 48% (Nov.) of the harbour seal's diet in Cowichan Bay was comprised of adult salmon (Bigg et. al. 1990). In 1988, the number of seals gradually increased from a low of 30 in April to a peak of about 100 in December. Olesiuk et al. (1990) estimated that harbour seals consume an estimated 9 tonnes of salmon annually in Cowichan Bay. Seals targetted primarily on Chinook and chum salmon. Based on these data, consumption of Chinook salmon could potentially range from 100 to 500 adults. These data were collected in 1988 when low flows in the Cowichan River persisted until the end of October. Predation likely increases with the time Chinook salmon remain in the estuary. These impacts are not accounted for in this assessment but will have slightly reduced the productivity rates estimated in this paper.

Biological Characteristics

Biological data for Chinook were typically collected from three sources: 1) hatchery broodstock sampling, 2) spawning ground sampling, and 3) random sampling of the native food fishery (Nagtegaal et al. 1994a). Cowichan hatchery staff randomly sample approximately 25% of the Chinook collected for broodstock and then selectively sample all remaining adipose-clipped Chinook. As part of the carcass mark-recapture program all Chinook recovered on the spawning ground are sampled. A biological observer interviews native fishers and a random sample of Chinook caught in the native food fishery are sampled. Since this is a voluntary program, sampling is dependent on the approval of the fisher and as such may introduce some sampling bias. Available Chinook are sampled for length, sex, age, and presence/absence of adipose fin-clip.
Chinook from the Cowichan R. stock mature primarily as 3 and 4 year old fish; 5 year olds usually comprise less than 2% of the returning adults. Age composition of returning spawners varies

considerably among years and is in a large part indicated by the numbers of returning Age-2 male Chinook ("jacks"). The proportion of females by age in the escapement has remained consistent among years. Age structure in the total terminal run since 1982 is presented in Appendix 3.

CWT and Cohort Analysis

Estimating production for wild populations of Chinook salmon is dependent on information derived from hatchery indicator stocks. Ocean exploitation, terminal harvest rates, maturation rates and survival rates were estimated and inferred for brood years 1981 to 2000, using a cohort reconstruction procedure based on CWT recoveries of Cowichan River hatchery production.

Annual CWT recoveries from ocean fisheries are maintained in the Mark-Recovery database at the Pacific Biological Station. Annual CWT recoveries from the hatchery and river are maintained in a Salmonid Enhancement Program database (Habitat and Enhancement Branch, Vancouver, B.C.). For the Cowichan River, in-river recoveries are maintained by return year, sampling location, and tag code (Appendix 4). The estimated number of each tag code recovered was based on sample sizes (broodstock, Native catch, deadpitch by location) and the estimated number of Chinook in each location. For example, in broodstock samples the expansion for each tag recovered (i.e., observed recovery) was normally one since all fish were examined for tags. However, the upper river deadpitch sampling examines only a portion of the estimated return. The estimated number of tags is then determined by dividing the observed recoveries in a sample by the portion of the escapement sampled. Estimated recoveries by tag code were determined within sample location and summed over locations. The estimated annual recoveries in the total return to the Cowichan River provided the escapement data used in calculating cohort analyses for each brood year with adequate tagging. The list of tag codes used by brood year is provided in Appendix 5.

The cohort model used is documented in Appendix 2 of Starr and Argue (1991) and as modified by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC, TCCHINOOK (99)-2. The cohort model was modified by the CTC to account for the Chinook non-retention fisheries implemented in Canada during 1996. Modifications are documented in Appendix G of TCCHINOOK (99)-2.

Two refinements to the cohort analysis procedures were implemented to more accurately determine impacts on this stock. These were: definition of terminal sport recoveries (so that these do not inflate the estimated cohort sizes by age), and implementation of revised incidental morality rates as reported by the PSC (1997). Tags from the Cowichan River that were recovered after the first statistical week in August and in Statistical areas (Areas 17-10 through 17-17, Areas 18 and 19A, and sub-areas 29-45 and 29-25) were included as terminal sport recoveries. Incidental mortality rates applied were:

Gear:	Sub-Legal sized Chinook	Legal sized Chinook
Troll (1973-1997)	27.2%	22.8%
Troll (1998-current)	23.6%	20.1%
Sport (1973-1980)	39.1%	39.1%
Sport (1980-current)	19.2%	19.2%
Net (gillnet plus seine)	90% (not changed)	90%

For each brood year, cohort analysis provides information on:

a) annual distribution of catch and total fishing mortalities by fishery and age;
b) cohort size and survival rate by age (1-natural mortality rate at age *i*); and
c) ocean (catch or total fishing mortality) and total exploitation rates by fishery and age.

Further, in this assessment, results of the cohort analyses are applied to the age-structured terminal return to estimate the total (hatchery and wild) production from each brood year. The process reconstructs total production from a brood year by expanding the observed terminal run-at-age back through terminal fisheries and ocean fisheries using age and fishery-specific exploitation rates. In order to reduce the variation attributed to return of Jacks and changes in fishery regulations (eg. size limit effects by age), the measure of total production applied in this assessment is the production of Age-3 and older mature Chinook expected in the absence of fishing. Production of Age-2 Chinook is included but is expressed as the expected number of mature Chinook based on Age-2 Adult Equivalence (AEQ) factors estimated in the cohort analysis (i.e., the probability that an Age-2 Chinook would survive to spawn if it were not caught).

Production Function Analysis

To analyze the stock and recruitment data, the two-parameter Ricker model (Ricker 1975) with multiplicative, log-normally distributed error was utilized. The log-linearized form of Ricker's model has the form of:

$$\log(R_t/S_t)=\log(\alpha)-\beta S_t+\varepsilon \qquad \textbf{\textit{equation 1}}$$

where R_t is the production in year class t, S_t is the number of spawners that produced them, α is the density independent productivity parameter, β the density-dependent parameter, and ε represents process error with mean 0 and variance σ_ε^2.

In the case where additional information is available, such as environmental variables or fishery management interventions, the additional information can be modeled by incorporating covariates to the Stock Recruit (S-R) model. The inclusion of a covariate should strengthen the estimated production relationship and improve the model fit. For instance, marine survival rates undoubtedly affect production by a year class. Production can be simultaneously regressed against both spawning abundance and brood marine survival rates (or their indices). The covariate can be added in a multiplicative fashion as a competitive factor in establishing production:

$$\log(R_t/S_t)=\log(\alpha)-\beta S_t+\gamma M_t+\varepsilon \qquad \textbf{\textit{equation 2}}$$

where M_t is the vector of covariates, such as the survival rate experienced by year class t. If M_t is an index, such as survival rates, the covariate is the log transform $\ln(M_t+1)$.

$$\log(R_t/S_t)=\log(\alpha)-\beta S_t+\gamma\log(M_t)+\varepsilon \qquad \textbf{\textit{equation 3}}$$

If there is a strong correlation between variation in survival rates and production, and a weak correlation between spawning abundance and these rates, the estimated relationship between production and spawning abundance will be strengthened and the model fit improved. The formulation above is relevant when covariates play no density dependent role in the production relationship.

For each model, diagnostics for homogeneity of variance and normality, and time series autocorrleation in model residuals were conducted. After the model was fitted and tested, it was used to make inference for the fishery management parameters; α, β, S_{msy} (spawner abundance that produces maximum sustained yield) and U_{msy} (the exploitation rate associated with S_{msy}). In this assessment, the parameter S_{msy} was estimated using two methods:

1. the approximations from Hilborn and Walters (1992)
   (i.e.) S_{msy} =a(0.5-0.07a)/b and U_{msy}=a(0.5-0.07a), and

2. S_{msy} was obtained by iteratively solving for the transcendental function:

   $1=(1-\beta S_{msy})\exp(\ln\alpha)\exp(-\beta S_{msy})\exp(\sigma_{\varepsilon}^{2}/2)$ (Ricker model)

   or

   $1=(1-\beta S_{msy})\exp(\ln\alpha)\exp(\Sigma_i\, \gamma_i\, \overline{Xi})\exp(-\beta S_{msy})\exp(\sigma_{\varepsilon}^{2}/2)$ (Ricker & covariate model)

Uncertainty about these parameters was investigated using non-parametric bootstrapping of the residuals from the regression. Using the bootstrap procedure, 1000 new samples of the residuals, each of the same size as the observed data, were drawn with replacement from the model residuals. A new set of dependent variables are generated by adding the residuals from the original regression to the predicted recruitment values from the S-R function. In this manner a new data set is created comprised of the original values of the independent variables (spawners and covariates) and simulated values for production. The new production values are then regressed against the original values of the independent variables to produce a new, simulated vector of parameter estimates. All bootstrap data sets that produced a determinate solution for S_{msy} by the iterative estimation procedure were included in the statistical summaries of the bootstrap distributions.

The 90% confidence interval can be obtained from the 5% and 95% quartiles from the ordered bootstrap sample (n=1000), with the exception that the upper and lower 0.5% of the samples were omitted due to their extreme values.

Spawner / Smolt Relationship

Modeled results for the production function are confounded with trends in marine survival and/or increasing interactions between hatchery-produced and naturally-produced Chinook in the spawning population. In order to remove the effect of marine survival an alternative approach explored the relationship between spawner abundance and wild smolt production. A wild smolt production index was estimated from total wild adult production and CWT estimates of smolt to adult survival. The wild smolt production index was substituted for recruitment in the two parameter Ricker model, and as such survival rates were incorporated directly rather than as a covariate. The S_{msy} was obtained by iteratively solving for the transcendental function.

Results

Terminal Run and Age Structure

The total terminal return, including spawning escapement, brood stock, and Native catches are documented in Table 1, and escapement plotted in Figure 3. Acquiring an accurate value for annual total terminal runs has proven to be a difficult job. Each year presented different problems and substantial professional judgement was needed to determine the escapement level even when we conducted fence counts and/or mark-recapture programs. Appendix 2 presents the historical record of the spawning escapement data available and Appendix 2c provides our recommended values that we have applied in this assessment.

Table 1. Summary of total terminal run estimated for fall Chinook salmon to the Cowichan River. (see footnotes for sources of this data and additional comments).

Return Year	Natural Spawners[a]		Brood stock[b]		Native Fishery[c]		Terminal Run	
	Age3+	Jacks	Age3+	Jacks	Age3+	Jacks	Age3+	Jacks
1981	5500	unk	282		1500	1500	7282	1500
1982	4500	2000	534	15	1000	1000	6034	3015
1983	4500	5460	242	15	250	1000	4992	6475
1984	5000	4042	278	15	355	700	5633	4757
1985	3500	2200	175	15	1000	1000	4675	3215
1986	1832	5890	315	15	800	800	2947	6705
1987	1937	2085	582	15	800	800	3319	2900
1988	6200	4216	678	71	681	450	7559	4737
1989	5000	995	535	94	1055	250	6590	1339
1990	5300	15198	326	8	820	150	6446	15356
1991	6000	1341	1408	347	250	70	8100	1758
1992	8500	4589	1750	89	260	12	10510	4690
1993	5058	5765	1972	228	295	22	7325	6015
1994	5050	13345	1357	145	345	227	6752	13717
1995	14300	10517	2149	512	533	120	16982	11149
1996	12980	6483	1616	258	810	150	15406	6891
1997	9845	6771	128	110	191	0	10164	6881
1998	4371	3065	1487	201	1073	0	6931	3266
1999	4500	1380	1610	13	233	89	6343	1482
2000	5109	1879	1529	43	89	0	6727	1922
2001	3282	1626	1732	0	918	120	5932	1746
2002	2505	1677	1610	6	1500	0	5615	1683
2003	2494	1822	862	14	825	0	4181	1836
2004	2226	1503	495	20	320	4	3041	1527

Footnotes:

a) Natural spawning values and basis from Appendix 2 of this report.

b) Brood stock values are hatchery records, 1981-1987 data provided by Barry Cordocedo (S.E.P., pers. comm.). Adult records in these years included Jacks but reliable records of the number of Jacks were not available. Usually only 10-15 Jacks were collected each year with the exception of the first few years of operation.

c) 1981-1987 data for Native catches provided by Fishery Officer records, 1983-1987 data based on combined surveys of the Fishery Officers and the Cowichan Band Management Unit. Data for 1988 and onward from contract observers and/or survey results provided by the Cowichan Band Management Unit. Values for Jack Chinook previous to 1988 are of unknown accuracy.

Escapements between 1985 and 1994 were only slightly better than those observed prior to the 1985 PST. The lowest escapements on record, 2147 and 2519 adult spawners (biased low) were observed in 1986 and 1987, respectively. In 1995 and 1996 spawning escapements doubled those previously observed. Unfortunately, the increases observed in 1995 and 1996 have not been maintained in recent years. Escapements in the last seven years have not achieved the existing escapement goal (7400). Age structure in the total terminal run is provided in Appendix 3.

Results of the Cohort Analysis

Catch Distribution

To calculate the annual distribution of total fishing mortalities, each brood year contributing to an annual catch must be represented by CWT groups. For the Cowichan Chinook stock, this limits the information for years prior to 1991, due to the absence of tagging in the 1984 and 1986 brood years. However, the majority of fishing mortality on this stock consistently occurred in the Strait of Georgia sport fishery. On average, total mortality of Cowichan Chinook in that sport fishery accounted for 34% of the annual production (total fishing mortality plus escapement) for this stock. Approximately 75% of this mortality occurs in the northern portion of the Strait of Georgia (Pacific Fishery Management Areas 13-16). When the Strait of Georgia troll fishery was operating, it also had significant catch of the stock, followed then by the southern BC net fisheries (this catch predominately occurred in the Johnstone Strait nets). Annual distributions of total fishing mortality, as a portion of the annual production, on Cowichan River fall Chinook are documented in Appendix 6.

Trends in Marine Survival Rates

Survival rates are estimated as the estimated tags in the Age-2 pre-fishery recruitment divided by the CWT tags released. The estimated survival rate for Cowichan Chinook released from the hatchery has varied between <1% to about 6% since the 1985 brood year (Figure 5). Since 1995 survival rates have on average been less than 1%.

Brood Exploitation Rates

Total exploitation rate (figure 6) is reported as the sum of reported catch and incidental mortality associated with fishing. Values are expressed in Adult Equivalence (the proportion of fish of a given age that in the absence of fishing would leave the ocean and return to the terminal area and spawn) and for both estimates the denominator includes total fishing mortality and total spawning escapement.

Exploitation rates on Cowichan Chinook reached a high of 88% for the 1985 brood year. As a result of conservation measures to reduce harvest rates on coho in the late 1990s exploitation rates on Cowichan fall Chinook were reduced to 30%. However exploitation rates on brood years following 1995 have gradually increased to over 70% (Figure 6) likely as a result of changing fishery dynamics due to loss of coho opportunity. Sport fishing pressure has been redirected to Chinook in the Northern Georgia Strait, west coast Vancouver Island, southern US, and the terminal area. Commercial fishing patterns were altered to avoid Thompson coho and WCVI Chinook stocks of concern. Consequently, while the Georgia Strait sport fishery continues to have the highest impact on Cowichan Chinook (since the late 1990's) other fisheries; Southern US net, terminal sport, WCVI troll and WCVI sport have increased harvest rates (Appendix 6). On average, incidental mortality has accounted for 24% of the total AEQ fishing mortality but reached a high of 29% in brood year 1999.

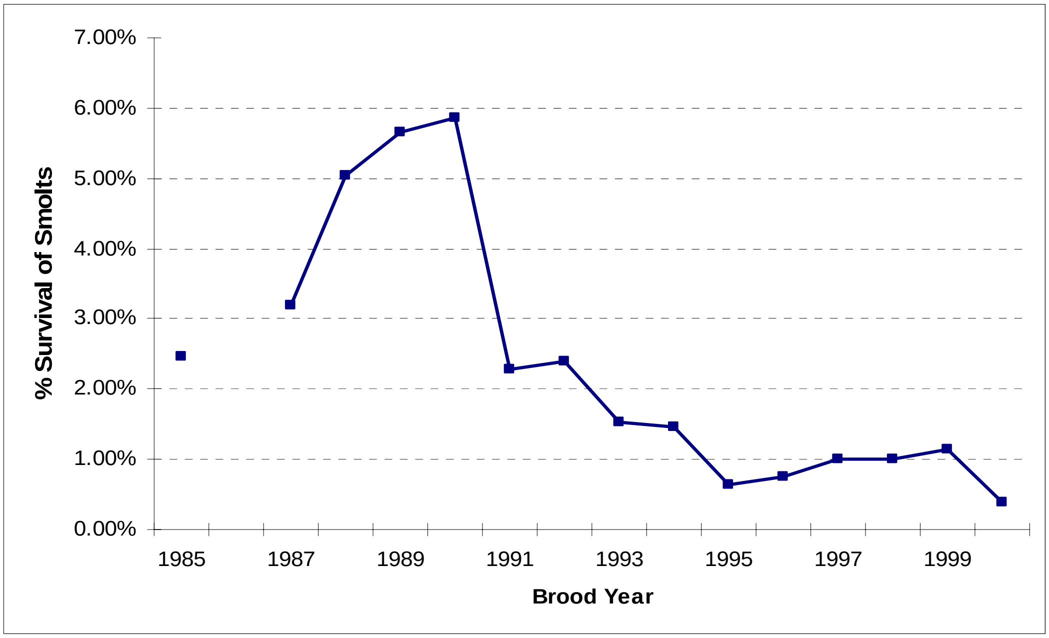


Figure 5. Estimated marine survival rates for Cowichan fall Chinook released from the Cowichan hatchery, brood years 1985 – 2000.

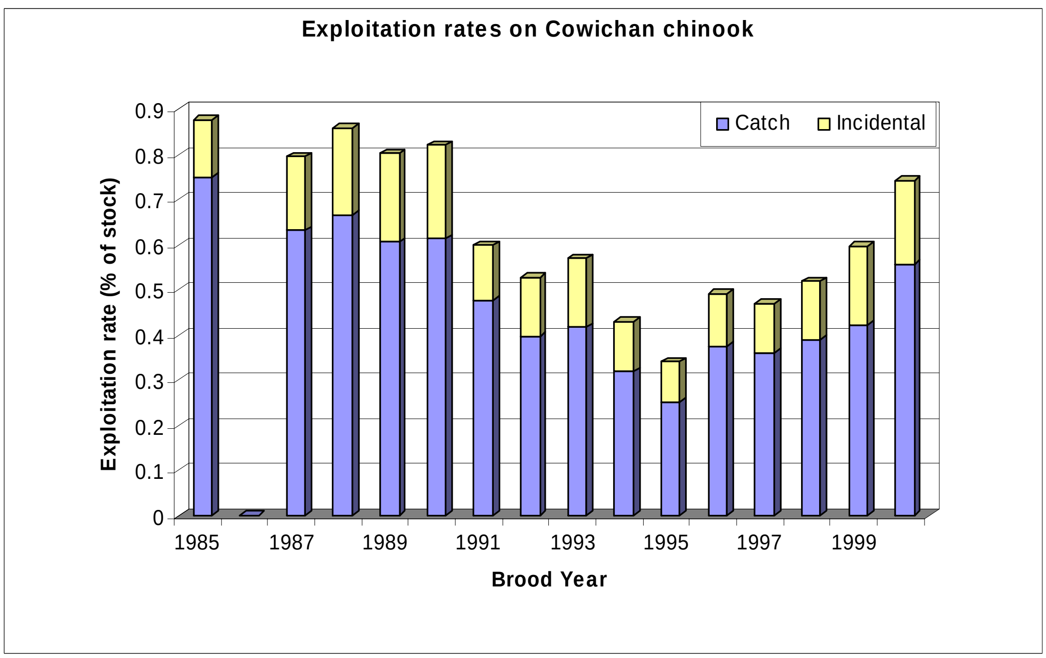


Figure 6. Total fishing mortality (catch and incidental mortality, AEQ total exploitation rates) on Cowichan fall Chinook salmon, for brood years with coded-wire tags and quantitative escapement sampling.

Results of the Production Function Analyses

Chinook production that has resulted from the naturally-spawning component of this population (since the 1981 brood year) has been estimated based on:

- annual estimates of the age-structured terminal run,
- exploitation rates and maturity rates by age, adult equivalence factors; each estimated via the cohort analysis,
- and annual estimates of the contribution of hatchery fish to the fish that spawn naturally.

A summary table of the numbers of spawners, estimated total production, brood year specific marine survival rates, and percentage of the spawners attributed to hatchery production is presented in Appendix 7. Data and the analyses are available in Excel 2002 workbooks and can be acquired from A. Tompkins (250-729-8382 or e-mail: tompkinsa@pac.dfo-mpo.gc.ca).

Conducting a stock-recruitment analysis on this data set involves a relatively short time series and the data contain a substantial amount of uncertainty. For example, we have not been able to quantify measurement error for this time series of data since various methods have been employed and estimates of recruits per spawner vary by over 25 times. Consequently, we assessed the results of three combinations of models and two data sets in order to examine an appropriate escapement goal for this stock (at this time).

Our initial assessment involved the Ricker stock/recruitment relationship (equation 1). The plot of the simple Ricker function clearly indicates the variability in this data and the clumping of most of the data in a limited range of the spawning escapement range (Figure 7).

As marine survival rates affect production and given the extent of hatchery production involved with this population, we also examined the influence of two covariates, marine survival (SR) and the proportion of hatchery fish in the natural spawning population (pHat, equation 3). Initially, we examined whether pHat was linearly related to recruits per spawner (Figure 8). The linear regression with the proportion hatchery was significant ($p = 0.006$, $R^2 = 0.489$), and each co-efficient in the regression was significant. The regression equation was:

$$\text{Log}(R/S) = 2.333 - 5.50\ \text{pHat}$$

The parameter values and measures of fit (probability values included in the brackets) for the Ricker model and the Ricker model plus marine survival or proportion hatchery as a covariate (equation 3) are presented in the following table.

Parameter estimates from models fitted to complete time series: Brood Years 1981-2000								
Model	Log(α)	β	γ	σ	R^2	Model p-value	S_{msy}	U_{msy}
Ricker Only	2.73 (0.000)	0.0002 (0.0009)		0.84	0.46	0.0009	3,724	0.89
Ricker +Survival Rate	2.252 (0.000)	0.0002 (0.106)	0.5611 (0.0054)	0.68	0.67	0.0001	5,127	0.81
Ricker + pHat	2.225 (0.0000)	0.0002 (0.0221)	-0.5183 (0.0166)	0.73	0.62	0.0003	5,281	0.81

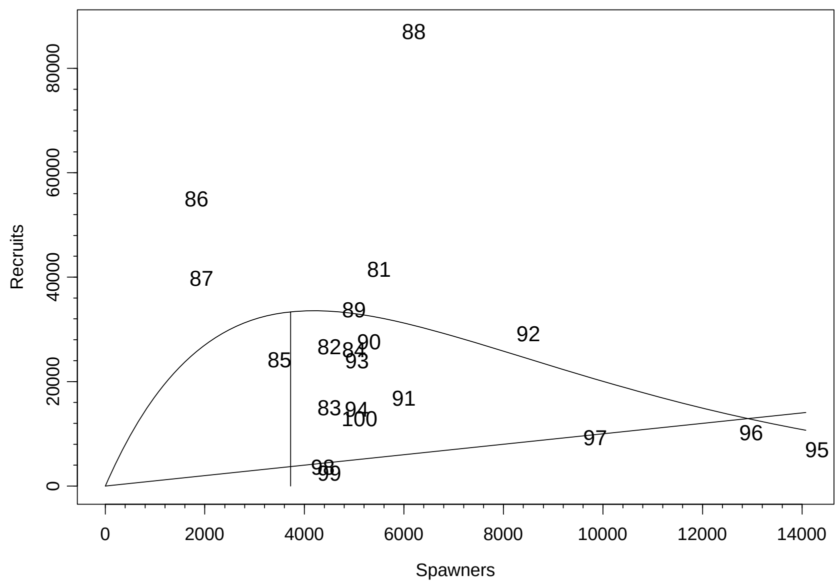


Figure 7. Ricker stock/recruitment relationship for the production data presented in Appendix 7. The solid vertical line indicates the location of the estimated optimal escapement value.

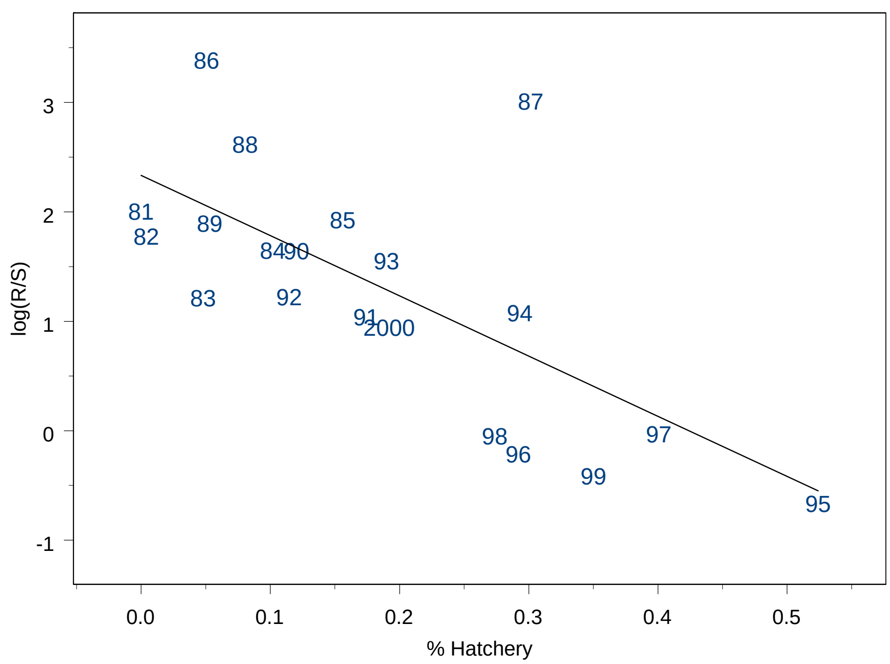


Figure 8. Linear regression of Log(Recruits/Spawner) versus proportion hatchery in the natural spawning population, data in summary Appendix 7. Symbols indicate brood year.

Although the Ricker model provides a statistically significant fit to these data, the fitted regression only accounted for 46% of the variation in recruits per spawner. The parameter values for the estimated function were unrealistic for a naturally spawning Chinook population. The estimated productivity for the stock would be almost 15 mature adults produced per spawner, the estimate of optimal spawners would be 3724, and the sustainable exploitation rate for maximum sustained yield (MSY) would be almost 90%! Furthermore, a plot of the residuals against brood year revealed serial correlation in the time series indicative of non-stationary production (Appendix 8a). Both autocorrelation and partial autocorrelation functions detected lag 1 autocorrelation. The presence of autocorrelation in the residuals resulting from the Ricker function suggested the model was not completely specified and estimates of S_{msy} had the potential for time-series bias.

The Ricker model plus either covariate provided a better fit than the Ricker model alone. Ricker with survival rate or proportion hatchery respectively, performed similarly (R^2 = .67 and .62) and provided similar estimates of optimal spawners (5100 and 5300).

Data Issues:
The data contain a substantial amount of uncertainty, particularly in the early years. Inspection of Figure 7 and review of the historical escapement data set suggested the early data points (1981-1984, 1986-1987) should be re-evaluated for inclusion in the stock recruit analysis. We concluded these data points should be precluded from this assessment based on the following rationale:

1. Prior to 1988 total escapement estimates were based on visual counts (swims or aerial surveys). Sampling of river spawners was not initiated until 1988 the same year fence counts were established. Consequently recovery of escapement CWTs for natural spawners prior to 1988 are not available. Estimates of escapement for these years are either 4500 or 5000, were generated with information from other stocks, or are believed to be biased low. Because many of the escapements after this period center about 5000, escapements from 1981-84 represent redundant information at best. Statistics given for early brood years in Appendix 7 likely contribute more measurement error than information.
2. Also, hatchery releases from the 1984 and 1986 brood years were not tagged, so there is no direct information on survival or exploitation rates for those broods. Survival rates were estimated based on observed tags and cohort analysis from other years. The absence of coded-wire tagging of the 1984 and 1986 brood years reduces the accuracy of hatchery contributions to the natural spawning population from these broods (estimates were made by averaging the year before and after by age-class).
3. The accuracy of the spawner enumerations during 1986-1987 is likely the poorest in our data record (see Appendix 2). Extreme low flows for all of September and October limited movement of Chinook up-stream. Enumeration was then limited by heavy flows in November. However, we can not preclude that Chinook were able to migrate and spawn in these November conditions. The standardized swim survey employed by the fishery officers has likely led to incorrect estimation of spawners because the distribution of fish was affected by the flow, underestimating escapement during low water flow conditions and overestimating during high water flow conditions.
4. The parameters estimates when the data points are included are simply unrealistic for a natural population of salmon.

For these reasons, and since four additional brood years: 1997 to 2000, have become available since the existing interim goal was established, brood years 1981-1984, and 1986-1987 were excluded from the second data set.

Revised Dataset

Removing the 1981-1984 and 1986-1987 brood years from this analysis produced variable results. Only the model with pHat as a covariate showed an improved fit (R2=.79) but the resulting estimate, Smsy=20,903, was unrealistic given the historic recorded range of adult spawner abundance. The Ricker model performed poorer using the revised dataset. The model with survival rate as a covariate was basically unchanged in explaining variance in production (R2 =0.66) but the residual standard error was reduced (σ = .41). The Ricker model with survival rate as a covariate was selected as the model that best fit the revised dataset because it consistently behaved well for all measures of performance: estimating parameters, explaining variance in production, reducing residual standard error and eliminating time series autocorrelation (Appendix 8b).

Parameter estimates from models fitted to reduced time series: Brood Years 1985, 1988-2000								
Model	Log(α) (prob)	β (prob)	γ (prob)	σ	R^2	Model p-value	S_{msy}	U_{msy}
Ricker Only	2.09 (0.003)	0.0002 (0.037)		0.87	0.31	0.04	4,763	0.81
Ricker +Survival Rate	1.65 (0.003)	0.0001 (0.089)	0.64 (0.006)	0.41	0.66	0.003	6,514	0.69
Ricker + pHat	1.1 (0.01)	0.0000 (0.64)	-0.8504 (0.0004)	0.51	0.79	0.0002	20,903	0.51

Figure 9 compares the fit of the Ricker model to the fit of S/R model with stock and survival rate as a covariate. In the covariate model the optimal spawning stock size = 6,514 and the maximum sustainable exploitation rate = 0.66.

To quantify the uncertainty in the parameters estimated from the Ricker function with survival rate as the covariate (equation 3), bootstrapping of the residuals of the fitted model was conducted. For each simulation a vector of residuals was drawn randomly with replacement from the set of residuals from the original regression and added to the predicted production values (R). A new dataset was created comprised of the original values for the independent variables (spawning abundance and covariate) and the simulated values for production. Production was then regressed against the independent variables to produce a new vector of parameter estimates. One thousand bootstrap simulations were performed to generate distributions for the optimum escapement goal (S_{msy}, Figure 10a) and the maximum sustained exploitation rates at S_{msy} (U_{msy}, Figure 10b). All bootstrap data sets that produced a determinate solution for S_{msy} by the iterative estimation procedure were included in the statistical summaries of the bootstrap distributions. In these simulations a few extreme values occurred at each end of the distributions. Statistics in the table below excluded the upper and lower 0.05% of the values (N= 985).

MSY	Model Estimate	Bootstrap Mean	Bootstrap StDev	Bootstrap CI
S_{msy}	6514	7922	6434	(4159, 14962)
U_{msy}	0.69	0.67	0.085	(0.52, 0.80)

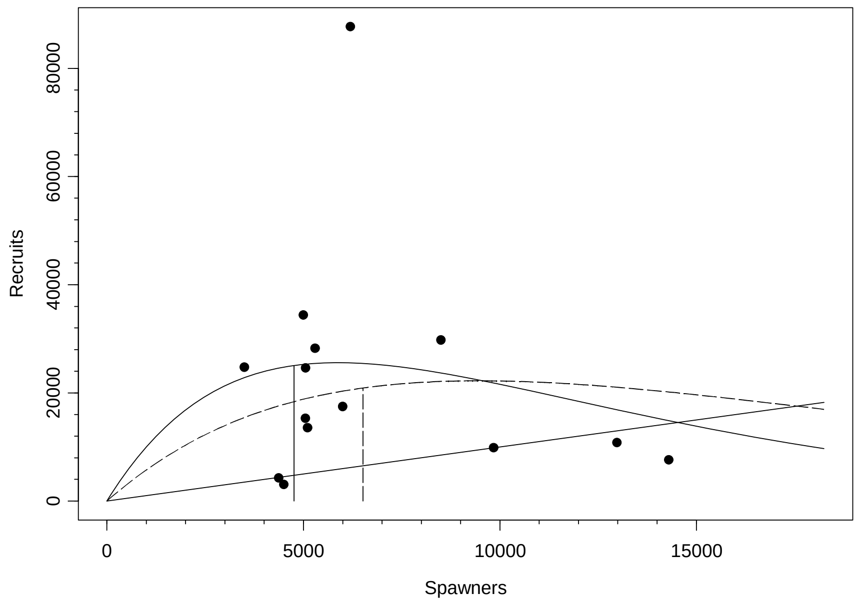
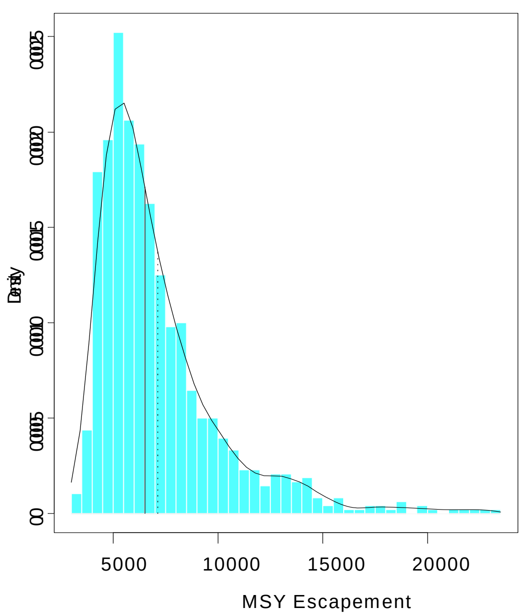


Figure 9. Ricker stock/recruitment plots for Ricker model (Stock only, solid line) and the S/R model with Stock and log(SR + 1) as the covariate (dashed line).



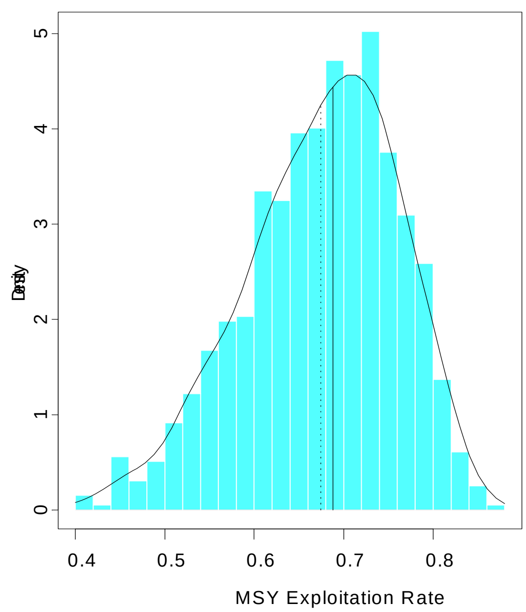


Figure 10a. S_{msy}; **Figure 10b. U_{msy}**

In the plots of these bootstrap simulations, the vertical solid line is the observed (parameters from the fitted model) and the dashed lines are the mean from the bootstrapped samples.

Based on the Ricker model, excluding the 1981-1984 and 1986-1987 brood years, with the survival rate to age 2 as a covariate (log transformed, equation3) the biologically-based escapement goal for adult fall Chinook in the Cowichan River was estimated to be 6,514 (90% CI = 4159, 14962). The associated maximum sustainable exploitation rate at S_{msy} was estimated to be 0.69 (90% CI = 0.52, 0.80). These results are consistent with those reported by Riddell et al. in 2000 (model estimate 6573, bootstrap mean 7405). However in the previous analysis, the bootstrap mean was incorrectly adopted as the escapement goal. The original model estimate, not the bootstrap mean, is the preferred estimate of spawning abundance that produces MSY, even though the former statistic contains some uncorrected bias (Efron and Tibshirani 1993, TCChinook (99)-3). The difference between the bootstrap mean and the original estimate is itself an estimate of the bias in the original estimate. That bias is positive, so using the bootstrap mean would potentially double the bias.

Smolt Production

When the wild smolt production index was substituted for recruits in the Ricker stock recruit function the estimated optimal escapement value was almost 14,000 spawners. This value is more than twice the estimate based on adult production produced by the Ricker model with survival rate as a covariate. The model accounts for only 13% of the variation and productivity was constant over the range of spawner abundance observed (p=0.21).

Model	Log(α)	β	σ	R^2	Model p-value	S_{msy}
Ricker (probability)	5.52 (0.000)	0.0001 (0.21)	0.41	0.13	0.21	13981

Inspection of Figure 11 shows a wide range in wild smolt production at escapements in the range of 4000-5000. Productivity of natural spawners ranged from 60 to 665 smolts per spawner (ln(smolts per spawner) = 4.1-6.5). Productivity was not significantly related to spawner abundance (Figure 12). However the relationship between marine survival and total smolt production had a significant negative slope (Figure 13).

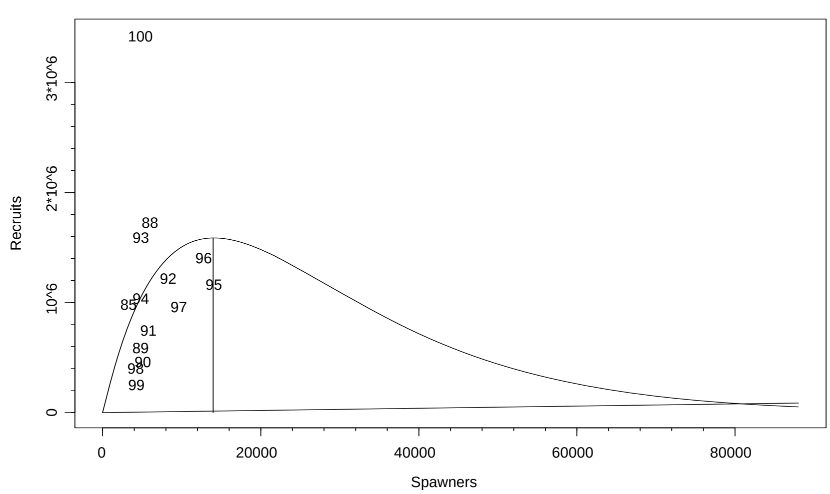


Figure 11. Ricker stock/recruitment relationship for wild smolt production data presented in Appendix 9. The solid vertical line indicates the location of the estimated optimal escapement value.

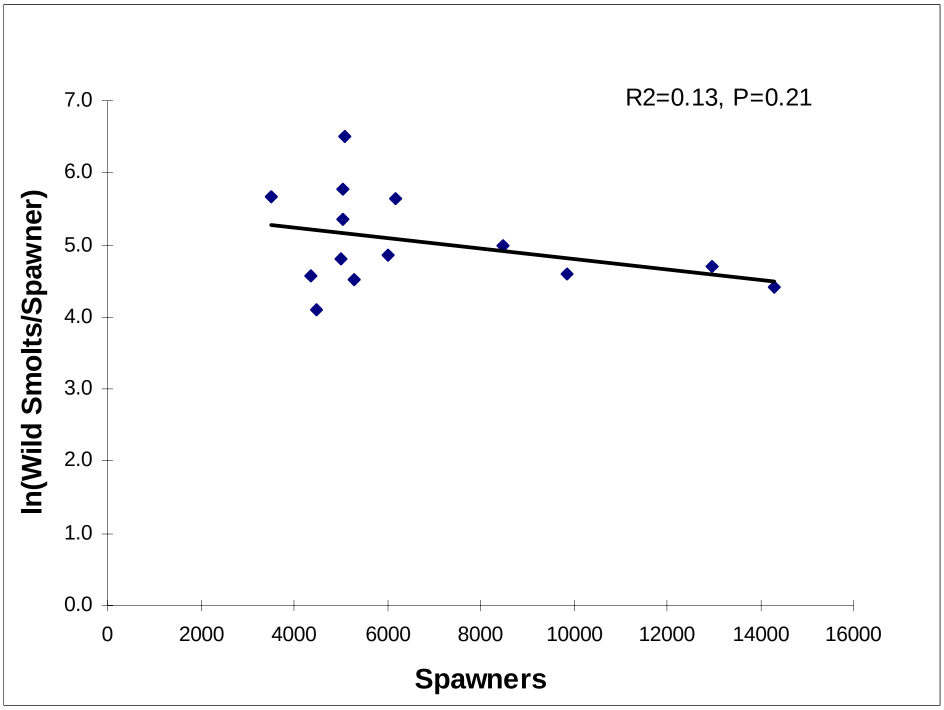


Figure 12. Productivity of natural spawners over range of observed spawner abundance.

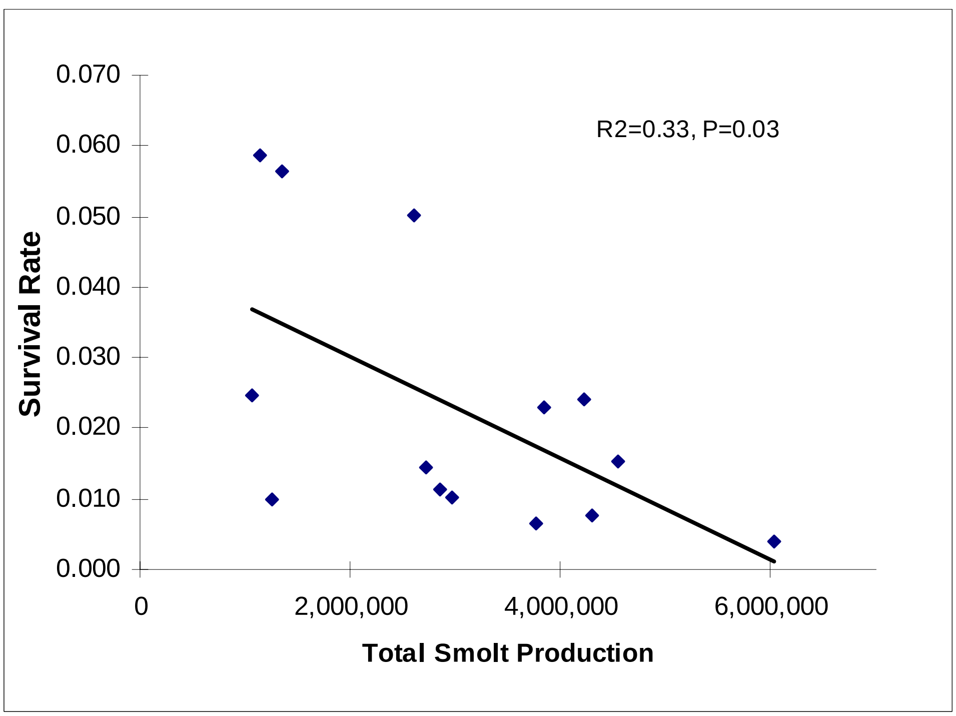


Figure 13. Survival rate versus total smolt production (hatchery releases and wild production).

Discussion

This assessment incorporated spawner recruit data available to 2004 and reevaluated the interim biologically-based escapement goal for Cowichan River fall Chinook, a naturally-spawning population in the lower Strait of Georgia. As previously noted this stock is not solely a natural population but is supplemented with production from the Cowichan CEDP hatchery. Production from this facility has contributed to increased numbers of Chinook spawning naturally and enabled the annual tagging of Chinook for assessment, but it also complicates interpretation and application of this assessment. For example, this assessment indicates that productivity of the naturally-spawning population decreased for brood years of larger spawning population sizes (1995 and 1996). For those years, we also noted that the proportion of hatchery fish in the natural spawning population had increased considerably and that marine survival for hatchery fish (produced in the same brood years) had decreased substantially (Figure 14). The low hatchery release from the 1997 brood year did not result in increased survival but the first brood year with reduced hatchery contribution (age 3 fish in 2000) showed increased natural productivity. Consequently, we are left with the uncertainty that our results may be consistent with a density-dependent production function, or confounded with trends in marine survival and/or increasing interactions between hatchery-produced and naturally-produced Chinook in the spawning population or as smolts in the estuary.

The determination of an optimal escapement goal is limited by the data available. Although 20 years of stock recruit data are available (1981 to 2000) only 14 years provide meaningful data. Data for brood years with the greatest uncertainty, 1981-1984, and 1986-1987, were left out of this current analysis. Since the interim escapement goal was established in 2000 four additional brood years (1997 - 2000) have been documented and utilized in this stock recruit analysis. Based on these revised data the optimal escapement was estimated to be 6,514 naturally-spawning adult Chinook (90% confidence interval 4200 to 15000). This estimate is similar to the results from the previous assessment (Riddell et al. 2000 model estimate) and consistent with the escapement goal of ~6600 developed by Parken et al 2004, using a habitat based model.

However, the data contain a substantial amount of uncertainty that can't be quantified. There are several indications that given the limitations in the data this estimate may underestimate the potential production from this stock:

1. An alternative method, substituting smolt production for recruits in the stock recruit function (incorporates CWT estimates of smolt-to adult survival directly in the estimate rather than as a covariate) suggests the estimate of S_{msy} is ~14,000. In the range of spawners observed, there was no effect of spawner abundance on wild smolt production.
2. The lack of density dependence on production is supported by the assessment of downstream juvenile migrations conducted in the Cowichan River (Nagtegaal et al. 1997a). The brood years of largest escapements, 1995 and 1997, resulted in some of the largest egg/fry survivals (8-12%, range 1.5 to 12.7%, Appendix 10) measured since 1990. Both years involved numbers of females exceeding our estimated goal. It should also be noted that the 1995 brood year experienced the lowest productivity (0.53) and the second lowest marine survival (0.64) in this time series. This suggests that some factor in the early marine environment may also be influential and that further investigation is required.
3. A preliminary assessment of spawning habitat indicates that, in the upper river alone, there is approximately 140,000 square meters of available spawning area (D. Nagtegaal, pers. comm.). The quality of this area has not been fully assessed, but conservative application of area per redd and/or suitability of habitats would still indicate that the numbers of females supported could be 6000-8000.

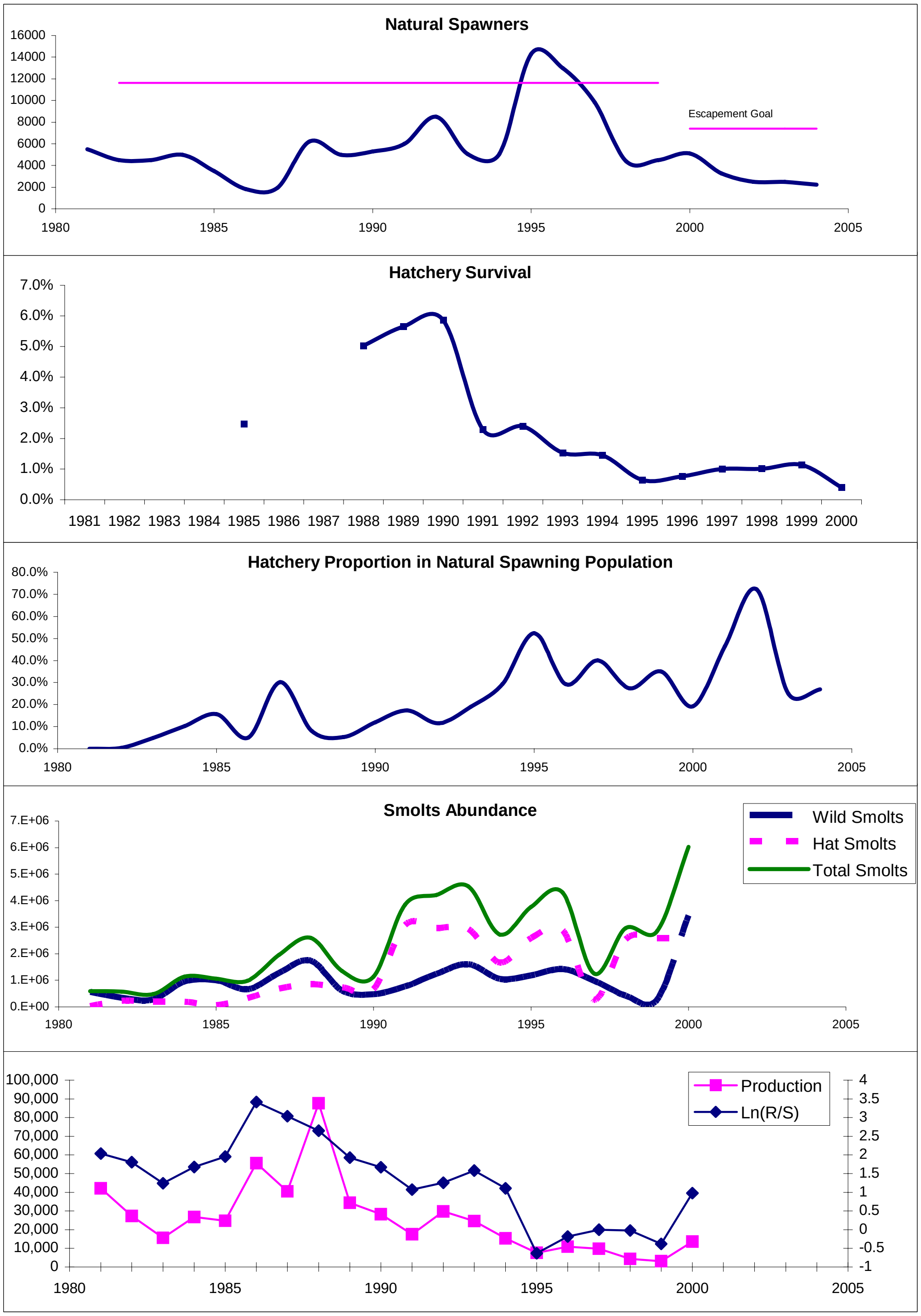


Figure 14. **1981-2000 Time series of Cowichan Chinook data: spawner abundance, hatchery survival rates, proportion hatchery in the natural spawning population, smolt abundance, and productivity (adults per spawner).**

4. The contrast in observed spawning abundance at 4.1 is at the low end of the range for reliable estimates of S_{msy} and most of the observed escapements were between 4,000-6,000 spawners. When contrast is small, the estimate of S_{msy} may be determined by process error, an extreme environmental event, or measurement error, not by the underlying relationship between spawner abundance and production. When stock recruit analysis is based on a short time series, with little contrast in spawning stock sizes and non-representative sampling at low spawning stock sizes, the resulting estimates tend to overestimate U_{msy} and underestimate S_{msy}.

Comparison of ratios of wild / hatchery Chinook causes additional concern. Estimating production for the wild population relies on information derived from the tagged hatchery population. The results from cohort analysis using CWT hatchery fish (exploitation and maturation rates) are applied to the age-structured terminal wild return to estimate total production. Wild smolt abundance was subsequently derived from reconstructed production and hatchery survival rates. However if we compare the ratio of wild to hatchery abundance as smolts relative to adult return, the ratio at return is much higher (Appendix 9). The data cast doubt on our assumption that hatchery fish represent the wild population, or alternatively, suggest our sampling program may be biased (underestimating hatchery contribution in the terminal return).

A cautionary approach is recommended for the management of this stock. Present population sizes are a conservation concern, and recall that a significant portion of the return is from hatchery production. At the present poor marine survival rates (i.e., the last six brood year's survival to Age 2 recruitment was 1% or less), Cowichan fall Chinook salmon will not be able to replace spawning populations. If poor survivals persist, the number of naturally-spawning fish in this population will continue to decline. In 2004, total escapement was 2721 adult Chinook (2226 natural spawning, 495 broodstock subsequently lost), a level similar to that experienced in 1986-1987 when survival rates were three to eight times higher. At the same time ocean fishery exploitation rates have increased to 70%. Preliminary reports for 2005 escapement indicate approximately 2500 adult spawners (1600 natural spawners, 900 hatchery brood stock) and 1000 jacks (S. Baillie pers.comm.). The current trends in escapement and fishery exploitation on this population should be assessed to prevent a serious conservation issue.

Recommendations

These authors recommend:

1. The biologically-based escapement goal for Cowichan fall Chinook should be revised from 7,400 to 6,500 naturally-spawning adult Chinook (90% CI =4159, 14962). The latter value is based on the mean value of the bootstrap simulations for the Ricker model plus survival rate (log transformed) used as a covariate.
2. The present programs of coded-wire tagging and intensive escapement monitoring should be maintained, both to continue to examine production dynamics in this stock and to monitor the developing conservation risk (given present poor marine survivals).
3. An independent estimate of the enhanced component of the return (other than CWT based estimate) should be carried out to verify the hatchery contribution to the terminal run.
4. The current level of hatchery production should be evaluated given the observed high contribution of hatchery origin fish to the spawning population.
5. Monitoring of juvenile freshwater survival should be re-established since it provides an independent measure of stock productivity.
6. Since 1995, brood year exploitation rates on this stock have steadily increased while escapements have continued to decline to well below the escapement goal. It is recommended that extreme caution

be exercised when planning fisheries that significantly impact this stock, until such time as productivity rates are known to be increasing.

7. A management plan should be established to investigate the production potential from escapements exceeding this point estimate (6500) and the effects of enhancement on wild stock productivity.

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Appendix 1. Summary Recommendations PSARC Salmon Subcommittee meeting October 19 – 20, 2004, Nanaimo, B.C

S2004-08 A biologically based escapement goal for Cowichan River fall Chinook Salmon – Update.
A. Tompkins, B. Riddell, D. Nagtegaal.

<u>Subcommittee Discussion</u>

The assessment was an update of existing methodology using data available to 2003. In keeping with the PSARC terms-of-reference dealing with updates, no pre-meeting reviews were obtained. An interim escapement goal of 7,400 (95% C.I. 4,185- 18,915) was accepted by PSARC in May 2000 based on available stock-recruitment data. Consistent with the original report, the present analysis used spawning stock size and two covariates (marine survival and hatchery contribution to the natural spawners) to assess impacts on recruitment and recommended an escapement goal of 8,600 spawners (90% CI=5,004-28,386).

The review by the Subcommittee identified two concerns with the present analysis. First, an alternative analysis of the data was suggested that includes CWT estimates of smolt-to-adult survival directly in the estimate of recruitment rather than as a covariate. This would allow an evaluation of the effect of the hatchery covariate independent of potential density-dependant marine effects. Since 1990, the enhanced contribution to the naturally-spawning population has averaged 35% but ranged as high as 70% (2002) based on the incidence of coded wire tagged Chinook recovered in the escapement.

Second, the Subcommittee identified a statistical issue that needs to be resolved when estimating point estimates of S_{msy} from stock-recruitment analysis with log-normal errors. The working paper estimate of the mean S_{msy} based on the standard back-transformation to correct for bias was 8,600 spawners. The mean of the distribution of S_{msy} based on bootstrapped sampling of the residuals was 12,000 spawners. The Subcommittee could not conclude which method was superior and suggested that this needs to be resolved before acceptance of the proposed S_{msy} target. Some Subcommittee members argued for establishing guidelines for conducting stock assessments that would deal with these sorts of statistical issues and, more generally, the relevance of advice based on the median or mean of parameter estimates.

Although the analysis was not a report on stock status, the data presented in the paper showed that recent wild Chinook escapement estimates have dropped to near record lows and exploitation rate estimates have concurrently increased. The Subcommittee concluded that based on the information in the paper, the status of Cowichan Chinook is poor. One meeting participant with a habitat perspective argued that spawning success of Chinook entering the Cowichan River might be improved through flow regulation of the river. The Subcommittee noted that the Cowichan River stock is a prominant component of the Lower Strait of Georgia (LSG) indicator and warrants a priority assessment of the stock status of LSG Chinook. The Subcommittee further noted that the last LSG assessment was done in 1998.

<u>Subcommittee Conclusions</u>

- The revised escapement goal provided in the Update was not accepted.
- The Subcommittee concluded that a re-analysis of the stock-recruitment data be undertaken to decouple density dependent ocean survival effects from potential hatchery effects.
- The statistical issue identified by the Subcommittee for estimating point estimates of S_{msy} or other metrics derived from log-normal distributions should be resolved.

- Although the Update was not a report on stock status of Cowichan River Chinook, the recent historical low escapements are cause for conservation concern.
- The present CWT and escapement monitoring should continue.

Subcommittee Recommendations

1. The Subcommittee recommended that a new stock-recruitment analysis that allows a direct assessment of hatchery effects on natural production be carried out and reported in a future PSARC working paper.

2. The Subcommittee recommended that the request for advice include input from the Ocean - Habitat Sector to consider alternative habitat-based mitigation methods for increasing spawning success such as water flow management.

3. The Subcommittee recommended that the stock status of Lower Strait of Georgia Chinook be undertaken as soon as possible given the recent historical low Chinook escapement to the Cowichan River.

Appendix 2. Basis of naturally-spawning escapement estimates for the Cowichan River Fall Chinook, 1981-2000.

Appendix 2a. Swim survey or Fishery Officer estimates (survey S = swim, H = Helicopter, F = Fixed wing overflight)

Year	# of Surveys	Survey Dates & Cnt. (Peak count of Age 3+)		Expanded # Chinook	Expan. factor	Final Esc. Estimate	Comments:
1981	4 S, 1H	Oct. 23	3200	5000	1.56	5500	Total escapement noted to likely be low
1982	2S, 1H, 1F	Nov. 08	no value given	4000		4500	Based on F survey, uncertain value, basis of expansion unknown
1983	6S	Oct. 25	1113	4500	4.04	4500	Good flows for surveys
1984	9S	Oct. 23	1300	5000	3.85	5000	High flows, adult counts uncertain
1985	8S	Oct. 31	934	3500	3.75	3500	High flows, poor visibility
1986	6S, 1H	Nov. 08	491	1200	2.44	1200	Steady low flows all fall, passage efficiency unknown, relatively low expansion factor applied
1987	5S	Nov. 06	649	1200	1.85	1200	Lowest recorded fall flows, passage efficiency unknown, relatively low expansion factor applied
1988	5S	Oct. 14	2076	4000	1.93	5500	Good agreement between surveys
1989	5S	Nov. 01	2267	5000	2.21	5000	Low flows, good counting until late October
1990	4S	Oct. 19	2382	5000	2.10	5300	Good agreement between surveys
1991	4S	Oct. 31	3502	9000	2.57	10000	Major flood very early, expansions uncertain
1992	8S	Oct. 27	797	4500	5.65	7500	Officers adjusted upwards based on fence counts, due to high flows in late Oct.
1993	5S	Nov. 04	987	3355	3.40	5200	First year of Cowichan River Management surveys
1994	5S	Oct. 26	1450	4930	3.40	5500	Surveys by Cowichan River Management program
1995	2S	Oct. 25	1798	6653	3.70	15500	Major flood, counts uncertain
1996	6S	Oct. 22	1699	5776	3.4	6500	Major flood, counts uncertain
1997	5S	Oct. 23	1831	6225	3.4	6500	Major flood in mid-Oct., counts uncertain
1998	4S	Oct. 26	1260	4284	3.4	4284	Low flows through October, then above average in Nov.
1999	1S	early Oct.					no estimates made due to limited surveys
2000	1S	Sept. 13	25	85	3.4		no estimates made due to limited surveys
2001	3S	Oct. 23	940	3196	3.4	3282	Low flows, good counting until late October

Year	# of Surveys	Survey Dates & Cnt. (Peak count of Age 3+)		Expanded # Chinook	Expan. factor	Final Esc. Estimate	Comments:
2002	1S	Oct. 25	418	1421	3.4	2505	Low flows, good counting until late October
2003							No swim surveys conducted
2004	1S	Oct. 7	58			2226	1 survey no escapement estimate
2005							No swim survey

Appendix 2b. Counting weir and/or Mark/Recapture (M/R) estimates of escapements

Year	Weir operation:		Weir Counts:		M/R	Estimated Popn.	Comments
	Start	End	Adults	Jacks	Adult est.	Size	
1988	Sept. 10	Nov. 02	5164	4244	NA	6200 Age 3+ 5000 Jacks	
1989	Sept. 13	Oct. 22	1324	1022	NA	No estimate made	Low flows, weir lost on first flood
1990	Sept. 12	Oct. 25	4164	15200	NA	4900 Age 3+ 17000 Jacks	
1991	Aug. 19	Nov. 11	2375	1626	NA	6000 Age 3+ 4100 Jacks	Major flood very early, minimum popn. Estimate
1992	Aug. 18	Oct. 30	7740	3694	7230	8500 Age 3+ 4000 Jacks	Minimum popn estimated, mark /recapture too few tag recoveries
1993	Aug. 22	Nov. 22	5058	5768	4601	5058 Age 3+ 5768 Jacks	First year of complete weir counts
1994	Aug. 15	Nov. 13	5050	13381	3848	5050 Age 3+ 13381 Jacks	Complete weir counts
1995	Sept. 08	Oct. 18	10715	7906	6329	14300 Age 3+ 8000 Jacks	Major flood mid-Oct., expanded counts based on cumulative run curve
1996	Aug. 30	Oct. 23	10385	5752	9411	12980 Age 3+ 6000 Jacks	Flooding again, expanded counts based on cumulative run curve
1997	Sept. 05	Oct. 03	4349	2374	5547	7876 Age 3+ 3500 Jacks	Major flood in early Oct., Mark/Recapture estimates used assuming a 50:50 sex ratio
1998	Sept. 05	Nov. 08	4328	3065	2087	4760 Age 3+ 3065 Jacks	Weir count + 10% for returns after Nov. 8th, no inflation of Jacks
1999	Aug. 27	Oct. 30	3836	1290	3440	4500 Age 3+ 1500 Jacks	Weir count +15% for returns after Oct.30th , mark re-capture less than these values
2000	Sep. 8	Oct. 24	4667	1391	2364	5109 Age 3+ 4110 jacks	Weir count +15% for returns after Oct.24th , mark re-capture less than these values
2001	Sep. 4	Nov. 1	3361	1454	3869	3282 Age 3+ 2535 jacks	Weir count +15% for returns after Nov. 1th , mark re-capture greater than these

Year	Weir operation: Start	End	Chinook Counts: Adults	Jacks	M/R Adult est.	Estimated Popn. Size	Comments
							values (due to high water)
2002	Sep. 3	Nov. 13	2745	1667	1245	2505 Age 3+ 1683 Jacks	Complete weir count.
2003	Sep. 8	Oct. 16	2015	2710	1781	1843 Age 3+ 2723 Jacks	Flood Oct 16, poor account, expanded based on mark recapture and run timing curve
2004	Sep. 10	Oct. 27	2002	1003	1898	1898 Age 3+ 1387 Jacks	
2005	Sep. 6	Oct. 26	1292	992	NA		Good weir count. Does not include 235 adults and 53 jacks moved above fence.

Appendix 2c. Recommended estimate of spawning escapement based on the above summary tables. Visual estimates indicate use of the swim or over-flight data.

Year	Basis of Escapement estimate	Recommended escapement values: Age 3+	Jacks	Comments:
1981	Visual est.	5500	Unknown	Total escapement noted to likely be low, Jacks not expanded
1982	Visual est.	4500	Unknown (2000)	Based on F survey, uncertain value, basis of expansion unknown, no estimate of Jacks, 2000 Jacks based on brood stock sampling
1983	Visual est.	4500	5460	Good flows for surveys, Jack estimated based on 1.5x the adult expansion factor times the recorded count of 901 Jacks
1984	Visual est.	5000	4042	High flows, adult counts uncertain; Jack estimated based on 2x the adult expansion factor times the recorded count of 525 Jacks
1985	Visual est.	3500	2200	High flows, poor visibility; Jack estimated based on 2x the adult expansion factor times the recorded count of 293 Jacks
1986	Visual est.	1832	5890	Steady low flows all fall, passage efficiency unknown, estimate assumes 67% counting efficiency, 50% fish available to count
1987	Visual est.	1937	2085	Lowest recorded fall flows, passage efficiency unknown, estimate assumes 67% counting efficiency, 50% fish available to count
1988	Combined	6200	5000	Good agreement between surveys, escapement increased to allow for early entry of Chinook and after weir removed
1989	Visual est.	5000	2000	Low flows, good counting until late October but weir lost suddenly on first flood and high winds (leaf litter), values of less confidence than previous two years
1990	Combined	5300	17000	Good agreement between surveys
1991	Weir plus early swim surveys	6000	4100	Major flood very early (Labour Day weekend), expansions uncertain; estimate based on Officer expansions of first swim surveys and weir counts after Sept. 10
1992	Weir	8500	4000	Weir count to late October plus allowance for late entry of Chinook, Chinook still passing when weir lost.
1993	Weir	5058	5768	First year of complete weir coverage
1994	Weir	5050	13381	Complete weir coverage
1995	Weir	14300	8000	Major flood, counts uncertain; used weir plus expansion based

				on cumulative run curve
Year	Basis of Escapement estimate	Recommended escapement values: Age 3+	Jacks	Comments:
1996	Weir	12980	6000	Major flood, counts uncertain; used weir plus expansion based on cumulative run curve
1997	Mark – Recapture of females	9845	3500	Major flood in early-Oct., counts and run curve uncertain; used M/R data assuming 50/50 sex ratio in upper river program area, and 20% Chinook distribution below the survey area (based on historical observations only).
1998	Weir counts	4371	3065	Weir count + 10% for returns after Nov. 8th, no inflation of Jacks
1999	Weir counts	4500	1500	Weir count + 15% for returns after Oct. 30th.
2000	Weir counts	5109	1457	Weir count +15% for returns after Oct.24th
2001	Weir counts	3282	1626	Weir count +15% for returns after Nov. 1st
2002	Weir counts	2505	1683	Complete weir count.
2003	Weir counts	2494	2723	Weir counts expanded for run after Oct 16.
2004	Weir counts	2226	1503	Weir counts expanded for run after Oct 27.
2005	Weir counts and transport upstream	1527	1045	Preliminary estimate.

Appendix 3. Age structure of fall Chinook salmon returning to the Cowichan river.
Age structure estimated for the total return including enhanced and naturally-produced Chinook. Enhanced contributions by age are removed (based recoveries of CWT) from the total population before expansion to total production conducted using the cohort analyses.

Return Year	Age Composition of Terminal Return			
	Age 2	**Age 3**	**Age 4**	**Age 5**
1982	33.32%	16.89%	46.61%	3.18%
1983	56.47%	18.84%	22.92%	1.77%
1984	45.78%	34.41%	17.71%	2.10%
1985	40.75%	35.53%	22.63%	1.10%
1986	69.47%	9.65%	17.38%	3.50%
1987	46.63%	5.69%	39.82%	7.85%
1988	42.21%	10.98%	45.65%	1.16%
1989	26.24%	50.90%	19.92%	2.95%
1990	72.69%	6.92%	18.28%	2.10%
1991	37.10%	29.57%	32.08%	1.26%
1992	28.07%	16.72%	53.33%	1.88%
1993	45.10%	26.16%	26.18%	2.56%
1994	67.07%	21.19%	10.65%	1.08%
1995	33.70%	46.73%	18.91%	0.66%
1996	29.38%	33.64%	36.28%	0.71%
1997	26.21%	47.39%	24.93%	1.47%
1998	32.36%	32.59%	34.27%	0.78%
1999	20.20%	48.87%	28.14%	2.80%
2000	19.73%	32.79%	44.60%	2.89%
2001	22.74%	45.51%	29.89%	1.87%
2002	23.06%	48.06%	27.76%	1.11%
2003	33.54%	52.34%	14.12%	0.00%
2004	33.43%	33.35%	28.04%	5.00%

Appendix 4. Terminal adult returns and coded wire tags recovered by year and sampling location. % refers to observed tags / return. Generally all broodstock returns were sampled. Only a portion of the natural spawners and Native Fishery were sampled.

Return Year	Natural Spawners Age3+	Natural Spawners CWT Obs	Natural Spawners CWT %	Brood stock Age3+	Brood stock CWT Obs	Brood stock CWT %	Native Fishery Age3+	Native Fishery CWT Obs	Native Fishery CWT %	Terminal Run Age3+	Terminal Run CWT Obs	Terminal Run CWT %
1981	5500			282			1500			7282		
1982	4500			534			1000			6034		
1983	4500			242			250			4992		
1984	5000			278			355			5633		
1985	3500			175	13	7.43%	1000			4675	13	0.28%
1986	1832			315	4	1.27%	800			2947	4	0.14%
1987	1937			582	15	2.58%	800			3319	15	0.45%
1988	6200			678	6	0.88%	681			7559	6	0.08%
1989	5000			535	5	0.93%	1055			6590	5	0.08%
1990	5300	1	0.02%	326	13	3.99%	820			6446	14	0.22%
1991	6000	72	1.20%	1408	199	14.13%	250	5	2.00%	7658	276	3.60%
1992	8500	64	0.75%	1750	145	8.29%	260			10510	209	1.99%
1993	5058	187	3.70%	1972	351	17.80%	295			7325	538	7.34%
1994	5050	24	0.48%	1357	91	6.71%	345	8	2.32%	6752	123	1.82%
1995	14300	23	0.16%	2149	118	5.49%	533			16982	141	0.83%
1996	12980	28	0.22%	1616	81	5.01%	810	2	0.25%	15406	111	0.72%
1997	9845	42	0.43%	128	8	6.25%	191			10164	50	0.49%
1998	4371	6	0.14%	1487	77	5.18%	1073			6931	83	1.20%
1999	4500	9	0.20%	1610	68	4.22%	233			6343	77	1.21%
2000	5109	19	0.37%	1529	115	7.52%	89			6727	134	1.99%
2001	3282	29	0.88%	1732	128	7.39%	918			5932	157	2.65%
2002	2505	3	0.12%	1610	133	8.26%	1500			5615	136	2.42%
2003	2494	13	0.52%	862	35	4.06%	825			4181	48	1.15%
2004	2226	10	0.45%	495	11	2.22%	320			3041	21	0.69%

Appendix 5. Coded-wire tag groups for Cowichan fall Chinook salmon that are used in the cohort analyses for this stock.

Tag code list by brood year	Tag code list by brood year	Tag code list by brood year
@85	@93	@2000
023803	181320	183216
023804	181321	183217
023911	181322	184539
@86 … no CWT applied	@94	184546
@87	181436	184547
024334	181437	
024729	181438	
024730	@95	
024735	182026	
024945	182027	
024946	182028	
@88	182029	
024860	182030	
025012	182031	
025013	@96	
025015	182740	
025016	182741	
025017	182742	
025523	182743	
025524	182744	
@89	182745	
020352	@97	
020522	182761	
020622	182762	
020623	182763	
020624	182801	
020938	182802	
020939	182803	
026103	182804	
@90	182805	
020336	@98	
020337	183109	
020338	183111	
020339	183112	
020340	183730	
020341	183731	
@91	183732	
180515	183733	
180516	@99	
180517	183119	
180518	183123	
@92	183124	
180210	183125	
180550	183126	
181042		
181044		

Appendix 6. Distribution of total fishing mortality on Cowichan River fall Chinook salmon.
Annual values are the portion of the total fishing mortality by fishery. Total fishing mortality and the portion of the stock in the spawning escapement are presented as separate columns.

Rec Yr	AK all gear	NCBC all gear	WCVI TROLL	GEO ST TROLL	SBC NET	SUS NET	WCVI SPORT	SUS Sport	GEO ST SPORT	TERMN SPORT	TOTAL CATCH	ESCAPE
1987	1.36	5.25	2.53	10.81	27.39	13.44	0.00	0.89	26.54	3.94	98.18	1.83
1988	2.38	2.98	1.74	29.43	1.31	4.87	0.00	2.59	40.26	3.83	90.44	9.56
1989	1.61	1.83	3.30	8.15	12.40	4.56	0.07	1.33	31.90	0.24	66.61	33.39
1990	0.03	2.91	3.02	16.24	11.35	5.40	0.10	2.70	41.67	1.09	88.87	11.12
1991	0.11	2.48	4.62	10.86	4.89	4.25	0.77	0.87	52.19	0.65	82.84	17.18
1992	0.19	2.32	9.62	19.91	4.13	1.53	1.31	1.19	47.84	0.41	89.91	10.10
1993	0.34	2.02	7.94	11.88	3.61	1.01	1.44	0.58	50.93	0.75	81.62	18.38
1994	0.57	0.78	4.31	4.51	7.69	5.07	0.95	0.82	37.24	2.41	66.83	33.16
1995	0.35	0.81	4.40	0.01	1.87	2.47	0.70	1.50	35.28	4.02	52.29	47.71
1996	0.63	0.83	0.14	0.00	0.68	1.66	1.19	5.02	44.63	2.47	57.37	42.64
1997	1.37	1.27	3.16	0.00	1.45	4.84	1.18	3.32	26.55	3.05	46.18	53.82
1998	3.64	1.14	0.63	0.00	0.45	5.71	1.72	0.06	24.72	7.59	45.78	54.22
1999	0.16	0.89	0.54	0.00	0.97	11.37	4.47	2.05	36.81	5.22	63.35	36.64
2000	1.69	0.22	1.95	0.00	0.04	8.18	5.32	3.42	18.11	6.12	45.12	54.88
2001	0.70	3.30	10.45	0.00	0.25	14.05	0.66	5.59	24.67	2.12	62.07	37.92
2002	1.09	4.03	4.52	0.00	0.12	3.40	0.83	5.23	23.41	10.32	53.62	46.39
2003	2.34	12.73	8.06	0.00	0.08	9.18	11.93	2.61	26.31	2.25	76.21	23.79
2004	0.97	6.88	13.90	0.00	2.10	7.70	18.30	0.00	21.63	3.24	77.22	22.78
avg 87-04	1.08	2.92	4.71	6.21	4.49	6.04	2.83	2.21	33.93	3.32	69.14	30.86
avg 95-04	1.29	3.21	4.78	0.00	0.80	6.86	4.63	2.88	28.21	4.64	57.92	42.08

Appendix 7. Summary table of data used in the estimation of production functions for Cowichan River fall Chinook salmon

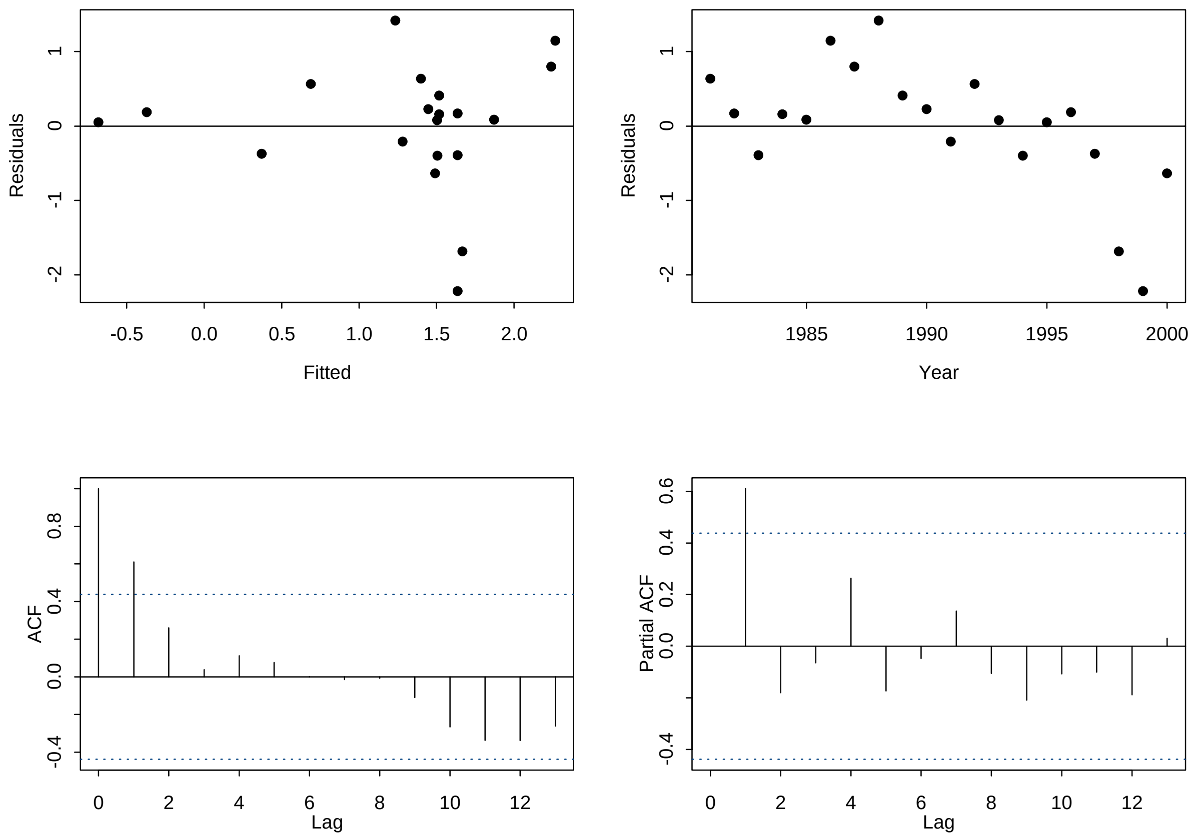
Brood Year	Natural Spawners	% Hatchery in Nat.Spawn	Total Adult Prod. (Fish.Mort + Esc.)	Returns per Spawner	LN(R/S)	Smolt Survival Age 2 Cohort est.	Survival Estimation Comments:
1981	5500	***0.00%***	***42129***	***7.66***	2.0360	***7.44%***	No escapement data, estimated
1982	4500	***0.40%***	***27326***	***6.07***	1.8038	***7.94%***	using observed tag recoveries and
1983	4500	***4.36%***	***15622***	***3.47***	1.2446	***5.71%***	cohort analysis from other years
1984	5000	***10.20%***	***26705***	***5.34***	1.6754	***2.80%***	NO CWT releases
1985	3500	16.81%	24727	7.06	1.9551	2.47%	
1986 a	1832	5.06%	55583	30.34	3.4125	***8.40%***	NO CWT releases
1987 b	1937	30.16%	40435	20.87	3.0385	3.19%	
1988	6200	8.05%	87700	14.15	2.6494	5.03%	
1989	5000	5.30%	34377	6.88	1.9279	5.65%	
1990	5300	12.02%	28244	5.33	1.6732	5.86%	
1991 c	6000	17.41%	17481	2.91	1.0693	2.29%	
1992 d	8500	11.46%	29758	3.50	1.2530	2.40%	
1993 e	5058	18.99%	24621	4.87	1.5826	1.53%	
1994	5050	29.31%	15288	3.03	1.1077	1.45%	
1995	14300	52.40%	7599	0.53	-0.6322	0.64%	
1996	12980	29.20%	10808	0.83	-0.1831	0.76%	
1997	9845	40.06%	9850	1.00	0.0005	1.00%	
1998	4371	27.39%	4283	0.98	-0.0203	1.01%	
1999	4500	35.03%	3068	0.68	-0.38	1.13%	
2000	5109	19.21%	13547	2.65	0.98	0.39%	Estimated based on survival observed through 2004 recoveries

a	exceptionally low water conditions followed by floods, very uncertain value
b	exceptionally low water conditions followed by floods, very uncertain value
c	very early high water, migration pattern very unusual
d	Otolith analysis of returns indicated enhanced portion of 61%
e	Otolith analysis of returns indicated enhanced portion of 55%

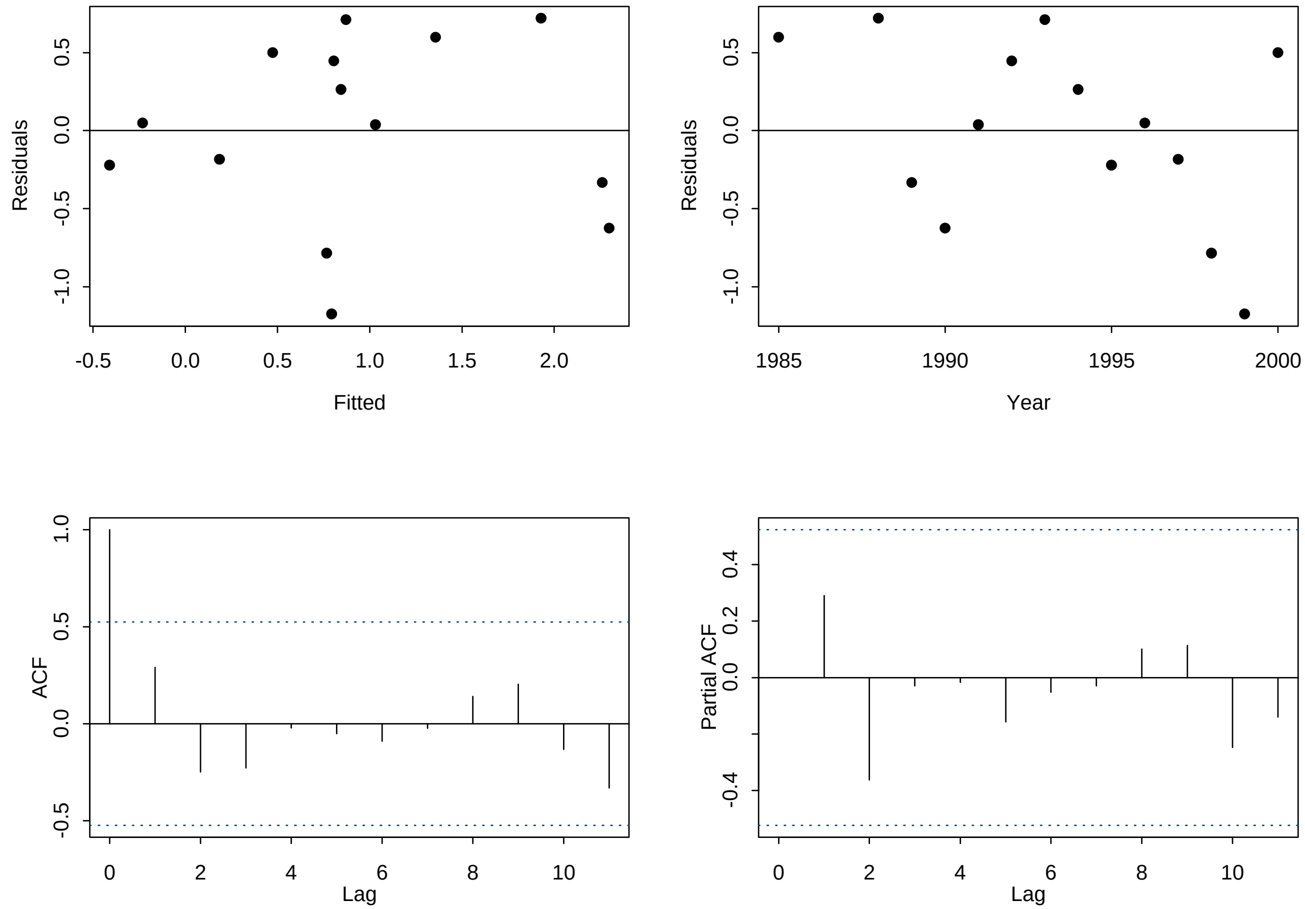
Appendix 8. Residual Diagnostic Plots

Row 1, Residuals plotted against predicted values; residuals plotted by broodyear.
Row 2, Plot of autocorrelation function and partial autocorrelation function of the stock-recruit relationship.

8a) Ricker stock-recruit function using brood years 1981-2000.



8b) Ricker stock-recruit function with survival rate as a covariate, using brood years 1985, 1988-2000.



Appendix 9. Wild smolt production index estimated from total wild adult production and CWT estimates of smolt to adult survival.

Brood Year	Natural Spawners	Natural Production	Survival Rate	Wild Smolts	Hatchery Releases	Total Smolts	Smolts Wild/Hatchery	Adult Return Wild/Hatchery	Ln(Wild Smolts /Spawner)
1985	3500	24,727	2.5%	1,001,085	63,886	1,064,971	15.67	22.05	5.656
1988	6200	87,700	5.0%	1,743,880	855,282	2,599,162	2.04	10.04	5.639
1989	5000	34,377	5.6%	608,545	736,939	1,345,484	0.83	3.17	4.802
1990	5300	28,244	5.9%	482,152	655,901	1,138,053	0.74	4.53	4.511
1991	6000	17,481	2.3%	763,686	3,079,120	3,842,806	0.25	1.36	4.846
1992	8500	29,758	2.4%	1,238,899	2,975,343	4,214,242	0.42	1.36	4.982
1993	5058	24,621	1.5%	1,610,273	2,931,614	4,541,887	0.55	2.04	5.763
1994	5050	15,288	1.4%	1,055,094	1,666,569	2,721,663	0.63	1.68	5.342
1995	14300	7,599	0.6%	1,181,849	2,588,958	3,770,807	0.46	2.21	4.415
1996	12980	10,808	0.8%	1,425,872	2,878,343	4,304,215	0.50	2.06	4.699
1997	9845	9,850	1.0%	981,079	270,494	1,251,573	3.63	9.83	4.602
1998	4371	4,283	1.0%	422,825	2,543,136	2,965,961	0.17	0.60	4.572
1999	4500	3,068	1.1%	271,264	2,582,056	2,853,320	0.09	0.19	4.099
2000	5109	13,547	0.4%	3,438,325	2,582,057	6,020,382	1.18	4.11	6.512

Appendix 10. Estimated egg to fry survival for wild Cowichan River Chinook from downstream trapping program.

Brood Year	Escapemen t	% females	Estimated Females	Fecundity	Estimated Eggs	Estimated Fry	Egg/fry Survival	Estimated fry		Egg/fry Survival	
								95% LCI	95% UCI	95% LCI	95% UCI
1990	5300	55	2915	4082	11899030	479856	4.03				
1991	6000	54	3240	3531	11440440	810240	7.08				
1992	8500	55	4675	4013	18760775	349298	1.86	250704	447891	1.34	2.39
1993	5058	59	2984	3861	11522073	173387	1.50	168365	178409	1.46	1.55
1994	5050	55	2778	3484	9676810	169828	1.75	153643	184382	1.59	1.91
1995	14300	51	7293	3501	25532793	3092626	12.11	264097 2	3544279	10.34	13.88
1997	9845	54	5316	3723	19792585	1638211	8.28	137609 7	1900324	6.95	9.60
1998	4371	47	2054	3826	7860020	173225	2.20	85159	193718	1.08	2.46
1999	4500	62	2777	3711	10303592	673726	6.54	546060	915723	5.30	8.89
2000	5109	57	2907	4098	11912972	664715	5.58	385911	757678	3.24	6.36
2001	3282	53	1748	4024	7039207	895180	12.72	480505	1340148	6.83	19.04