Assessment of the 2011 outmigration of coho smolts from the Englishman River and the contribution from the Clay Young channel

By

J.A. Taylor and M. Wright[1]

Submitted to

Community Fisheries
Development Centre

February 2012

---

[1] Fisheries and Oceans Canada, Resource Restoration, 1965 Island Diesel Way
Nanaimo, BC V9S 5W8

ABSTRACT

This report is the third in a series of studies that has assessed the overall coho smolt production in the Englishman River and quantified the portion originating in the extended Nature Trust side-channel, recently renamed the Clay Young Channel. A mark-recapture program, conducted between 31 March and 12 June, estimated total system production, while a collection weir was used to count out-migration from the channel, as well as supply marked fish for downstream recapture. Overall emigration from the Englishman system, during the study, was estimated to be 57,498 ± 5,851 smolts, of which 36% were contributed by the channel. The 2011 contribution from the Clay Young channel was comparable, if somewhat lower, than that observed in the two previous years (both estimated at 41%). Temporal stratification was incomplete, with recaptures of marked smolts from earlier release periods encountered on two occasions. This required the combination of two strata on the first occasion and pooling of strata 4 to 6 in the second. A parametric bootstrap estimate (57,900) showed excellent agreement with the pooled estimate, indicating that bias was small: bias adjusted confidence intervals were more precise (coefficient of variation 4.6) than those based on the normal approximation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

In common with many other streams on the East coast of Vancouver Island, the Englishman River experienced declining escapements of coho and other anadromous species in the 1980's. This situation stimulated efforts by the DFO, local community groups and other stakeholders, to assess limitations on freshwater production and identify opportunities for mitigation. Among the limiting factors that were identified were extreme fluctuations in seasonal flows that resulted in lack of summer off-channel rearing areas, and a paucity of winter low velocity refuge areas for pre-smolts (Miller 1997). The Englishman River Salmon Maintenance Plan (Hurst 1988) initiated construction of side-channel habitat in 1989 with the Weyerhaeuser Channel (then MacMillan Bloedel Ltd. Channel). A second channel, the Nature Trust Channel (then Fletcher Challenge Ltd. Channel and subsequently Timber West Channel), was constructed in 1992. In 2007 the Nature Trust channel was extended by 2.9 km, bringing the total available rearing habitat to 7.44 ha. This channel was re-named the Clay Young channel.

The functionality of these channels was examined through a number of population estimates of juvenile coho and other species produced in the 1990's. However, these employed different methodologies and were difficult to compare directly (Miller 1997). In 2001, the Englishman River was selected by the Pacific Salmon Endowment Fund Society (PSEFS) as one of the watersheds to be the focus of strategic recovery planning. An essential part of recovery evaluation is development of annual baseline data on coho and steelhead smolt abundances to permit assessment of trends in stock dynamics. The Englishman River Watershed Recovery Plan (ERWRP; Bocking and Gaboury 2001) initiated a series of programs to address these issues through the Community Fisheries Development Centre and local fisheries stream stewards. From 2002, these studies were ratified by ERWRP and funded by PSEF. More recently, since 2005, the Community Fisheries Development Centre (CFDC), in conjunction with a number of partners, including DFO, Pacific Salmon Commission, and Ministry of Transportation and

Highways has generated programs of similar design that have produced a series of population estimates for juvenile coho migration that form a baseline dataset to identify trends in stock dynamics. The present report describes the sixth project in this series.

2.0 METHODS

The 2011 program design was based on the stratified estimator described by Carlson et al. (1998) which was first used successfully in 2005 (Taylor 2005), replacing the pooled Petersen estimator employed in previous studies initiated in 1998 (Decker at al. 2003). This design utilizes a single RST site and using multiple mark types to guard against recovery interactions among recovery strata.

2.1 Study Area

The Englishman River flows from Mount Arrowsmith north-east for 28 km to enter the Strait of Georgia just south of Parksville, on Vancouver Island (Fig 1). It drains a watershed of approximately 324 km^2. The Englishman River primarily supports runs of coho *(Oncorhynchus. kisutch)* and chum *(O. keta)*, with less numerous escapements of chinook *(O. tshawytscha)*, pink *(O. gorbuscha)*, sockeye *(O. nerka)* steelhead *(O. mykiss)*, and anadromous cutthroat trout *(O. clarki)* (Brown et al. 1977). Anadromous fish can access 15.7 km of mainstem, up to the natural barrier of the Englishman River Falls. Additional anadromous fish habitat is provided by tributaries that increase the accessible length to 31 km (Decker et al. 2003). Among these, Centre Creek is a major contributor at 5.2 km long, representing approximately 17% of the total linear habitat.

The constructed side-channels provide 950 m (Weyerhaeuser) and 4,100 m (Nature Trust) of low gradient habitat in the lower 7 km of river. The Weyerhaeuser Channel is located approximately 6 km upstream from the estuary, on the south bank of the

mainstem. It was constructed as a groundwater channel in 1989, primarily to create summer and winter rearing habitat for juvenile coho. Although the initial constructed length was 600 m, a surface water intake was added and the overall length was extended in 1998 to include 2 spur channels for an overall wetted area of 6,000 m^2. In 2009, the river intake was damaged by flood waters and was subsequently removed in 2010.
The Nature Trust channel flows into the mainstem from the north bank, 1 km further upstream. Prior to its extension, the Nature Trust Channel provided 17,709 m^2 of low gradient (0.5%) habitat. Both channels derive flows from groundwater upwelling as well as controlled intake of river water. In combination, these channels represented a substantial contribution to coho production in the Englishman River system, with estimates ranging from 10% (2003, Schick and Decker 2004) to 25% (1998, Decker et al. 2003). Taylor (2005) estimated that the Nature Trust channel alone produced 9.3% of the production in the Englishman River system.

Extension of the Nature Trust channel to 7.44 ha of available rearing habitat generated unprecedented production, with 42% of the overall outmigration of coho smolts in 2009 originating in the newly named Clay Young channel. In 2010, 43% of a smaller migration was contributed by this area. The initial year represented an areal density of 0.43 smolts.m^{-2} for the portion of the channel delimited by the fence, exceeding the adopted biostandard of 0.4 smolts m^{-2}. In 2010, the density fell to 0.28 smolts m^{-2}.

2.2 Population Estimates

The stratified estimator described by Carlson et al. (1998) requires the application of unique mark types within designated marking periods to provide an estimate of capture probability (trap efficiency) over time, so that variation in efficiency can be addressed within the assumption of reasonable consistency in strata. This approach requires temporal stratification such that each trap efficiency trial is discretely paired with one capture period. An important element in planning is to determine the number of marks that must be released in order to achieve an appropriate level of accuracy for desired precision. Data from the 2010 study was used to generate the necessary parameters to calculate the required sample size for mark releases per stratum.

2.2.1 Calculation of mark releases

An appropriate goal for the level accuracy and precision was based on the recommendation of Robson and Regier (1964) for fairly accurate management work: an acceptable level of error is ±25% to be exceeded not greater than 5% of the time (α=0.05). A large number of smolts were expected to be available from Clay Young Channel, consequently, smolt numbers were not anticipated to be a limiting factor in any but the initial and final strata. The total relative error (r_h) was set at ±15% for 95% precision, as in previous years, and the calculated number of marks required to achieve this target was considered to be a minimum for the program.

Strata totals from the 2010 migration were used to estimate the proportion of the population encountered in each time period (ϕ_h) : a total of 5 strata were anticipated for 2011, given a provisional program duration of April 17 to June 7. These were 1%, 35%, 34%, 10% and 12%. A capture efficiency of 7.5% was assumed for the RST: the 2010 estimate was considerably higher at 11.2%, however, this value was much greater than in other years of the program and was considered not to be sufficiently conservative. Assuming a constant relative error (i.e. $r_1 = r_2 = ... = r_L$) then the expected stratum relative error (r_t) was estimated to be 29% from:

$$r_h = \frac{r_t}{\sqrt{\sum_{h=1}^{L} \phi_h^2}} \qquad (1)$$

and the number of marks required for release per stratum was calculated from:

$$M_h = \frac{K}{e_h(100)} \qquad (2)$$

where K is a constant described by the power function $y=3E+6x^{-1.8893}$ constructed for $\alpha=0.05$ from data given in Carlson et al. (1998). Solution of equation 2 indicates that the release of 678 marked fish is required as a minimum in each stratum.

2.2.2 Estimation method

The common Petersen estimator for population size, incorporating the Chapman (1951) modification for small sample bias, was used to provide an estimate of the overall population, including marked smolts, from release catch and recapture data. This estimator compensates for the tendency of the simple Petersen to overestimate the true population, particularly at low sample sizes, but requires recaptures to exceed 7 in a given stratum (Robson and Regier 1964). Strata estimates are from:

$$\hat{N}_h = \frac{(n_h+1)(M_h+1)}{m_h+1} - 1 \qquad (3)$$

where

$\hat{N}_h$ = estimate of population size for stratum h

M_h = number of marked smolts in stratum h

n_h = number of smolts in the RST catch in stratum h

m_h = number of recaptured marks in stratum h

Total smolt abundance is given by:

$$\hat{N} = \sum_{h=1}^{L} \hat{N}_h \qquad (4)$$

Given that predicted release of marks plus total catches in any RST was expected to be less than the anticipated population of smolts, the result is an approximately unbiased estimate.

The tally of marked smolts from RST catches represents sampling without replacement and, hence, the distribution of m_h for ranges of M_h and n_h, is hypergeometric. However, for populations greater than 100, simpler distributions, such as the binomial and normal, are satisfactory approximations (Robson and Regier 1964). Given the very large smolt population size, the normal approximation to the variance for $\hat{N}_h$ is adequate, in the form:

$$\mathrm{v}(\hat{N}_h) = \frac{(M_h+1)(n_h+1)(M_h-m_h)(n_h-m_h)}{(m_h+1)^2(m_h+2)} \qquad (5)$$

and the overall variance is:

$$v(\hat{N}) = \sum_{h=1}^{L} v(\hat{N}_h) \qquad (6)$$

(see Seber 1982:p60 for conditions to satisfy an approximately unbiased estimate of variance).

Approximate 95% confidence limits for $\hat{N}$ are:

$$\pm 1.96\sqrt{v(\hat{N})} \qquad (7)$$

Consistency in the capture efficiency of the RSTs through time was examined using a χ^2 contingency test. Randomness of the marking sample was tested by comparing the frequency distributions of marked and unmarked coho in size classes of 10mm (65 – 105mm), using a χ2 goodness of fit test after Seber (1982: p74). Similarly, size selective catchability was tested by comparing the distributions for recaptured and not recaptured smolts (χ2 Seber 1982: p71).

The precision of the estimate was assessed using the parametric method described by Carlson et al. (1998). The number of recaptures in each stratum (m_h) was treated as hyper geometrically distributed with parameters {$\hat{N}_h$, M_h and n_h}. One thousand random variates m_{jh} were drawn from the hypergeometric distribution using Systat© and used to calculate $\hat{N}_{jh}$ from equation 3. The precision of the estimate of population size was calculated as bias-corrected percentile confidence intervals (Efron and Tibshirani 1993), where:

$P_{UPPER/LOWER} = \Phi(2Z_O \pm 1.96)$ following calculation of the constant Z_o (p185).

2.2.3 Channel smolts sampling

Counts of the number of smolts that migrated from the Clay Young channel were made at a converging downstream weir: description of the construction and operation of a weir of this type can be found in Decker et al. (2003). Weir integrity was maintained throughout the project and, consequently, the total count accurately reflects population size for that portion of channel habitat located upstream: total catches and mark releases are provided in Appendix 1.

The weir was operated daily from 31 March to 12 June. All species collected at the weir were identified and tallied: this included steelhead salmon (*O. mykiss*) which were also enumerated at the mainstem sampling site (Appendix 2). Juvenile coho smolts were measured for fork length (mm) using a systematic procedure, based on a fixed sampling interval, i.e. every 4th or 5th fish, to sample randomly. Measurements were made on a daily basis to limit bias from sporadic sampling affecting estimates of mean fork length. Ninety-three percent of the steelhead smolts were measured at both the fence and the mainstem site. Water temperatures were collected daily at each weir and at the RST locations (Appendix 3).

Marking and subsequent release of smolts collected at the weir and recapture of marked and unmarked smolts from the lower river provided the data to estimate overall population size of the Englishman River outmigration. All juvenile coho > 65 mm were considered to be smolts. In previous years of the program, significant size selectivity by the rotary screw trap (RST) has been evident (Taylor and Wright 2010). An upper limit to marked smolts of 105mm was set in 2011 to see if lower trap efficiency in collecting larger more agile fish was a contributory factor in size comparisons between weir and RST captures.

Marking was performed on healthy smolts using a Pan Jet dental inoculator (Herbinger et al. 1990) to apply a sub-dermal tattoo of Alcian Blue dye to a fin. Three distinct marks, chosen for maximum visibility, were applied during the study: upper caudal fin, anal fin and lower caudal fin. The intent was for all marks released in each period to have moved through the system to the RST before further marks were released. Therefore, marking was concentrated at the beginning of each period to ensure that each release was discretely paired with one capture period. A flow-through holding box was used to estimate mortality of marked smolts in each release stratum: at least 100 smolts were held for 24 hr after which they were checked for mortalities.

Provisional sampling periods were established before the study started but these were adjusted to accommodate the minimum required mark releases and flow conditions in the mainstem. In 2011 we were able to initiate sampling earlier than in the previous year. We also continued until 12 June, a week later than in 2010. Consequently an additional release and recovery period was added to the program, bringing the total to 6.

2.2.4 Mainstem sampling

A 2 m diameter RST was installed in the Englishman River mainstem to trap juvenile coho migrating downstream and assess the mark-unmarked proportions of the migration. The RST was installed in the same location as in the 2010 study, on the east side of a 5 m wide gravel bar. Some movement of the RST was performed to accommodate changes in the hydrograph, however, for a majority of the program, at least 30% of the channel was sampled.

All smolts with a mark originating from Clay Young Channel were measured for fork length (mm). Unmarked smolts were also measured; sub-sampling was performed on large catches.

3.0 RESULTS AND DISCUSSION

3.1 Coho movement from the Clay Young side-channel

Daily counts of coho smolts migrating from the Clay Young side-channel were initiated on 31 March, at a water temperature of 6.5^0C. The concurrent mainstem temperature was 5.0^0C. During the study, water temperature in the side-channel ranged from 6^0C to 12.0^0C, while the mainstem was substantially cooler, reaching a maximum temperature of only 8.5^0C: this was lower than in either of the two previous years; 11^0C in 2010 (Taylor and Wright 2010) and 14^0C in 2009 (Taylor and Wright 2009). Similarly, average temperature in the channel was 8.7^0C versus 6.7^0C in the mainstem.

Perhaps due to the cold water temperature, significant smolt movement was not encountered until late April. Daily smolt migration is illustrated in Fig. 2. Peak migration occurred on May 23, with a count of 1,993 smolts, much lower than in the previous year (3,014). Similarly, in a ten day period between 16 May and 25 May, 45.5% of the total migration from the channel (9,090 smolts) was recorded (Appendix 1),lower than the maximum 10 day count in 2010 (11,676 smolts). A total of 4,788 smolts were marked for population estimation. Upper caudal, anal and lower caudal fin clips were used in rotation over the 6 periods of the program: releases by mark type and period are provided in Appendix 1. In all marking periods smolts were sufficiently numerous to exceed the minimum target (678 individuals) for release: in some cases substantially so with 1,050 smolts marked in period 5 (Appendix 1).

The total count of juvenile coho from the Clay Young Channel was 19,960 individuals: on the last day of sampling 142 were captured, indicating that the outmigration was incomplete and that this total is an underestimate of channel production, although likely a minor one. Adjusted for unsampled length, the estimate from the Clay Young channel is 20,499 smolts, or 5,000 smolts.km^{-1}. The total is slightly larger than in 2010 due to the greater length of the program and is substantially larger than the range of estimates provided by Marshall and Britton (1990) for coastal streams (1990: 363 – 3018 km^{-1}).

Totals of 1,211 upper caudal, 935 anal and 475 lower caudal marked smolts were measured during the program. Mean fork lengths for these groups, by marking period, is given in Table 1, the mean for all mark types was 93.3 mm (SD 7.1).

3.2 Mainstem sampling

The RST was fished between March 31 and June 12 with no periods where high discharge levels interfered with sampling. On several occasions, reduced catches resulted from a variety of objects being captured by the RST causing loss of fishing time. Unfortunately the degree of losses cannot be quantified, but they would be expected to have affected marked and unmarked fish equally. Consequently, the effect on the period estimates involved would be small. This is borne out by the occurrence of 3 blockages in Period 3, which had the highest capture efficiency in the program.

Over the course of the study a total of 4,313 smolts were captured, including 357 marks from 4,788 releases (Table 2). Figure 3 illustrates the cumulative proportional catches from the channel and in the RST and documents the agreement between mark releases and mainstem movement as well as the end of migration: the step pattern in the channel smolt releases reflects the pattern of mark application. The overall capture efficiency was 8.0% (values ranged from 3.0% to 10.4%), in excellent agreement with 7.5% anticipated in pre-study planning, but lower than in the 2010 study (mean 11.2%, range 1.2% to 18.5%, Taylor and Wright 2010). Capture probabilities demonstrated significant temporal variation (Pearson chi-square, $\chi 2 = 55.2$, df = 5, $p < 0.001$). As a result, the data could not be pooled over all periods to provide a Petersen estimate since the lack of temporal consistency suggests that such an estimate would incorporate substantial bias. However, some manipulation of temporal strata was necessitated by the recovery of a small number of marks in a succeeding release period.

A basic assumption of the estimation method is that marks are unique to a capture period (i.e. there is a low probability of recaptures from an efficiency trial occurring in a later stratum). In general, this has been true for the previous programs. However, in 2011, two instances of recaptures beyond the appropriate recapture period occurred, the first in period 2 (2 lower caudal marks from period 1) and the second in period 6 (1 anal mark from period 4). Two options were available, either to eliminate these recaptures or to accommodate them by collapsing the respective strata into a longer efficiency trial by respectively combining strata 1 and 2, and 4 through 6. The resulting period estimates could then be summed to provide an overall population estimate for the Englishman system. The effect of pooling was tested by comparing the estimate generated by excluding these recaptures, with successive estimates which included them. The various stratum estimates of population size and associated statistics derived from the combinations of catches and recaptures are presented in Table 1.

The initial estimate of total smolt numbers was 55,315 (95% CI 49,178 – 61,452). Precision for this estimate was excellent (± 5.67%) at almost 3 times the design target even though the recapture probability in the fifth stratum was low (3.0% with a coefficient of variation of 16.5% (Table 2a). Values of precision in the other strata ranged from 10.0% to 14.2%, due to generally high capture probabilities (range 5.5% - 10.4%).

A second calculation of population size was performed after pooling strata 1 and 2, to assess the extent to which reducing the number of trial periods would affect the estimate. The resulting estimate was 55,457 (95% CI 49,325 – 61.590), very similar to the original estimate, with a CV of 5.6. The degree of precision achieved in this case was examined using a parametric bootstrap technique (Carlson et al. 1998). This gave a slightly higher estimate of population size 56,533 and higher bias adjusted confidence range (95% CI 50,431 – 64,115), suggesting that there was a substantial difference from the normal approximation (Table 3). The bootstrap data show a significant departure from normality (Shapiro-Wilk statistic 0.98 p <0.001) and hence a shift in the confidence bounds as a result of the non-symmetrical distribution (Fig. 5a). Skewness was significant (the ratio of skewness 0.62 to its standard error 0.077 was 8.1), and indicates significantly longer tails than those for a normal distribution: in this case the right tail is elongated as can be seen in Figure 5a. The degree of kurtosis (kurtosis/se ratio 7.6) was also significant, in this case indicating a larger peak than a normal distribution. The influence of the poor capture probability in the fourth stratum (Table 2b) is probably seen in the departure from normalcy of the distribution. However, precision in the bootstrap was not greatly changed (CV 6.2%) and suggests that the pooling of periods 1 and 2 was appropriate.

Since the single anal clip recovered in period 6 was released in period 4, pooling over these periods was potentially more problematic. Ignoring this recovery, as in the example above, was a possible approach, but would have required some unknowable modification to the release total in period 4. Consequently, the estimate formed from both sets of pooling was examined (Table 2c). This estimate was somewhat higher than the others 57,498 (95% CI 51,647 – 63,349) with a slightly lower CV (5.2%) as would be expected as a fully pooled Petersen estimate was approached. In this case the bootstrap estimate was almost identical (57,900, 95% CI 53,543 – 63,891) and incorporated higher precision (CV 4.6% bias adjusted, Table 3). The distribution was again non-normal (Shapiro-Wilk statistic 0.986 p <0.001, skewness ratio 5.2, kurtosis ratio 1.5), but the excellent agreement with the pooled estimate is persuasive that limited bias accrues from combining the two sets of trial periods. Consequently, the second pooled estimate (Table 2c) was adopted as the most appropriate.

3.3 Sources of bias in the population estimate

One of the assumptions underlying the unbiased estimation of population size using a Petersen estimator is that all marks are recovered or move past the recapture site – this generally addresses the potential for marks from a release stratum to occur in more than one recovery period which was an unusual occurrence in this study. With a total of 3 marks being recovered in a stratum other than the release period it was the necessary to perform some pooling of strata, rather than to adjust the release totals to accommodate the possibility that movement of a portion of the outmigration was delayed by a variable amount: in the case of the anal clipped fish released on 22 or 23 May, movement to the RST required ~ 15 days rather than the usual 5. It would have been possible to reduce all releases by the ratio of late captures to total recaptures, but this would have been only a very minor correction (0.84%), and would have required the assumption that all marked fish were equally susceptible to delayed migration. This is not likely to have been the case. Consequently, although the variation in capture probabilities suggested that full pooling of all strata was not feasible, some combination of trial periods was possible, resulting in greater precision and containing a lower degree of bias than that incorporated in the un-pooled data. Bootstrapping indicated that recovery of marks in pooled strata agreed strongly with the underlying hypergeometric distribution and that precision was increased over that available from the normal approximation. The confidence intervals indicate that bias in the estimate was very low: the bias corrected 95% CI having a lower CV (4.6) than the uncorrected bounds (5.3).

Other assumptions that must be met for the unbiased estimation of population size using a Petersen estimator have been dealt with in detail in previous reports in this series (Taylor and Wright 2009, Taylor and Wright 2010) and are examined here briefly, in conjunction with assessment of compliance in the present study.

Short term mortality effects, such as between release and recapture, can lead to overestimation of population size. However, marking mortality was assessed during the program, and was found to be zero. Population closure requires that all of the population is encompassed within the sampling period. At the conclusion of the project a small number of smolts were still being caught in the RST (average 26 over 5 days), however in excess of 100 smolts were moving out of the Clay Young channel daily (equivalent average 129). While the effect on the estimate would be small, we acknowledge that sampling was concluded prior to cessation of migration, and, consequently, this contributed to underestimate of population size.

It was assumed that the release sites were sufficiently far from the capture sites that random mixing of marks with the unmarked smolt population would occur. Consequently, all smolts share the same probability of capture, or, an equal probability of being examined for marks. Issues of trap avoidance and potential effects of marking were addressed by comparing size frequencies of marked and unmarked catches. Comparisons of the size classes of marked versus unmarked smolts indicate the marked population was random with respect to size in all marking periods (Pearson $\chi 2$ range for individual periods 1.45 – 9.68, df = 6, p range = 0.96 – 0.14 Pearson $\chi 2$ for all periods combined = 10.70, df = 6, p = 0.10). There was also close agreement between the distributions of fork lengths of marked and unmarked smolts collected in the RST and a goodness of fit test on recaptured versus not recaptured smolts showed no size selectivity by the trap (Pearson $\chi 2$ = 11.85, df = 6, p = 0.07). The overall size distribution of recaptured smolts was identical to that of unmarked smolts captured in the RST (FL 91.4 mm versus 91.7 mm Table 1). Marked recaptures were also very similar to the overall average size of marks released from the Clay Young Channel (FL 93.3 mm).

Temporal stratification, as employed in the present study, can minimize bias from variability in capture probabilities, by compensating for events such as fluctuations in discharge. However, capture probability was depressed in the fifth release period (3.0%). Pooling reduced the degree to which this factor biased the overall estimate and the effect on precision appears to have been low.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The outmigration estimate of 57,498 smolts incorporated 20,499 smolts (corrected for the portion of the channel downstream of the weir) from the Clay Young Channel, a contribution of 35.7%, somewhat less than that in the previous year (43%). The 2011 program substantially improved on the design objective of ±15% accuracy (±10.2% with 95% confidence). This resulted from the availability of large numbers of smolts from the channel to increase the mark releases in a majority of time strata, combined with a higher than predicted capture efficiency by the RST. The 2011 mean value of 8.3% is higher than the 7.5% value used to calculate marking requirements but lower than the 10% recommended by Carlson et al. (1998): the latter has only been reached once in the present series of programs (11.2% in 2010). Nevertheless, bias was demonstrably low in the 2011 program. While there was poor catchability in the fifth stratum this did not result in a substantial loss of precision.

Earlier studies have estimated the contribution of sidechannel smolt production to the Englishman River system to lie between 15% (1999) and 25% (1998) (Decker et al. 2003). The unenhanced Nature Trust Channel alone contributed 14% in 2004 and 9% in 2005, Taylor 2005). More recently, the 2009 estimate of 41% of overall production (Taylor and Wright 2009), based on a counted population of 35,160 smolts that moved out of the Clay Young Channel, is the largest measured contribution (42% when the uncounted portion of channel production is included). However, the very large increase in production from the Englishman River in 2009 was not matched by that in the following year. In 2010, the outmigration declined to levels that were encountered in a majority of earlier programs (Taylor and Wright 2010), although the contribution from the Clay Young Channel remained high (43%). The current program (35.7%) represents an underestimate of smolt abundance as did the 2010 study: although it is probable that most of the late stage of outmigration was sampled in the mainstem, some degree of movement from the channel weir continued beyond the last sampling date. However, the degree of similarity in contemporary estimates of side-channel contribution suggests that the Clay Young side-channel provides a much larger contribution to the smolt output (average 39.9% SD 3.77) than would be expected on the basis of channel length (8% of the system length). Similarly, the degree to which the channel contributes to overall smolt production in the Englishman River has increased substantially over the last 4 to 5 years

1.0 ACKNOWLEDGEMENTS

Thanks to Ardith Turney, Community Fisheries Development Centre (CFDC) Central Vancouver Island, who co-ordinated the field program and performed sampling and marking of coho smolts at the Clay Young channel and RST site. She was assisted in the field by Jackie Morris and Hayden Gable. Bob Grant, CFDC administered the project contract and managed the crew. Doug Poole constructed the smolt fence and assisted with RST installation and removal. Mr. Poole’s capable assistance to keep the field equipment operational during the survey was greatly appreciated.. Thanks also to Mr. Kerry O’Conner for permission to access the lower RST site through his property. This project was funded by the Oceans, Habitat and Enhancement Branch of Fisheries and Oceans Canada and the BC Living Rivers Program.

6.0 REFERENCES

Arnason, A.N., C.W. Kirby, C.J. Schwartz and J.R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Can Tech. Rep. Fish. Aquat. Sci. 2106: 37p.

Brown, R. F., V. D. Chahley and D. G. Demontier. 1977. Preliminary catalogue of salmon streams and spawning escapements of Statistical Area 14 (Comox – Parksville). Fish. Env. Can. Fish. Mar. Serv. PAC/D-77-12.

Carlson, S.R., L.G. Coggins Jr. and C.O. Swanton. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fish. Res. Bull. 5(2):88-102.

Decker, A.S., Lightly, M.J. and A.A. Ladwig. 2003. The contribution of two constructed side-channels to coho salmon smolt production in the Englishman River. Can. Tech. Rep. Fish. Aquat. Sci. 2442 : 53p

Herbinger, C.M., G.F. Newkirk and S.T. Lanes. 1990. Individual marking of Atlantic salmon: evaluation of cold branding and jet injection of Alcian Blue in several fin locations. J. Fish. Biol. 36: 99-101.

Hurst, R. 1988. Englishman River salmon maintenance plan. Unpubl. Rpt. Department of Fisheries and Oceans.

Marshall, D.E., and E.W. Britton. 1990. Carrying capacity of coho salmon streams. Can. Manuscr. Rep. Fish. Aquat. Sci. 2058: 46p

Miller, L. 1997. Englishman River – the MacMillan Bloedel channel. A summary of present and historical biological data. Unpubl. Rpt. Habitat and Enhancement Branch, Department of Fisheries and Oceans.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can. 191. 382p.

Robson, D.S. and H.A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Trans. Amer. Fish. Soc. 93 (3):215 – 226.

Seber, G.A.F. 1982. The estimation of animal abundance. 2nd ed. Griffin, London.

Schick, J. and A.S. Decker. 2003. 2002 update for the Englishman River coho smolt enumeration program. Unpubl. Rpt. By Decker and Associates for Fisheries and Oceans Canada. 22p.

Taylor, J. A. 2005. Assessment of the 2005 outmigration of juvenile coho from the Englishman River. Unpubl. Rpt. for Community Fisheries Development Centre. 31p.

Taylor, J.A. and M. Wright. 2009. Assessment of the 2009 outmigration of coho salmon smolts from the Englishman River Unpubl. Rpt. for Community Fisheries Development Centre. 35p.

Taylor, J.A. and M. Wright. 2010. Assessment of off channel habitat to the production of coho in the Englishman River Unpubl. Rpt. for Community Fisheries Development Centre. 31p.

Table 1. Summary of coho smolt fork length (mm) by mark type measured at the Clay Young Channel and from the RST captures. The order of mark types corresponds to marking strata.

Site	Mark	n	mean FL	min FL	max FL	SD
Clay Young	UC[1]	759	93.6	61	135	6.0
	A[2]	526	94.4	64	135	6.1
	LC[3]	124	94.3	70	114	6.9
	A	409	92.0	69	126	7.6
	UC	452	91.4	70	125	8.9
	LC	351	94.9	68	146	8.2
	All marks	2621	93.3	64	146	7.1
RST	UC	54	92.1	72	110	9.4
	A	64	94.6	76	115	8.5
	LC	81	93.0	70	110	8.7
	A	21	90.8	74	110	8.9
	UC	77	87.1	70	108	8.6
	LC	39	90.9	77	107	9.4
	NM[4]	881	90.8	62	136	11.1
	All marks	336	91.4	70	115	9.2
	All smolts	1217	91.7	62	136	11.2

[1] UC = upper caudal fin periods 1 and 5, [2] A = anal fin periods 2 and 4, [3] LC = lower caudal fin periods 3 and 6, [4] NM = no mark

Table 2. Estimates of population size derived from recovery sampling by the rotary screw trap a) with elimination of marks captured outside the marking period b) with combined recapture periods 1 and 2 and c) with combined periods 5 and 6. Capture probabilities (trap efficiencies) are provided by mark group.

a)

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	upper 95% CL	lower 95% CL	CV	capture probability
08-May	312	748	59	3907	4753	3062	11.0	7.9%
14-May	620	700	65	6596	8017	5175	11.0	9.3%
21-May	1411	800	83	13464	16091	10838	10.0	10.4%
28-May	1288	800	79	12906	15489	10324	10.2	9.9%
03-Jun	417	1050	31	13729	18161	9296	16.5	3.0%
12-Jun	265	690	38	4713	6024	3402	14.2	5.5%
Total	4313	4788	355	55,315	61,452	49,178	5.7	8.1%

b)

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	upper 95% CL	lower 95% CL	CV	capture probability
14-May	932	1448	126	10645	12282	9008	7.8	8.7%
21-May	1411	800	83	13464	16091	10838	10.0	10.4%
28-May	1288	800	79	12906	15489	10324	10.2	9.9%
03-Jun	417	1050	31	13729	18161	9296	16.5	3.0%
12-Jun	265	690	38	4713	6024	3402	14.2	5.5%
Total	4313	4788	357	55,457	61,590	49,325	5.6	8.0%

c)

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	upper 95% CL	lower 95% CL	CV	capture probability
14-May	932	1448	126	10645	12282	9008	7.8	8.7%
21-May	1411	800	83	13464	16091	10838	10.0	10.4%
12-Jun	1970	2540	149	33389	38354	28423	7.6	5.9%
Total	4313	4788	358	57,498	63,349	51,647	5.2	8.3%

Table 3. Comparison of levels of precision obtained from unmodified temporal strata and from pooled strata. based on the normal approximation and bootstrapping. Bootstrap estimates were based on the hypergeometric distribution and 95% confidence intervals are provided in uncorrected and bias corrected form. Relative precision is assessed by the coefficient of variation (CV).

Technique	Strata pooled	Estimate	95% C I	CV
Normal approximation	none	55,315	49,178 – 61,452	5.7
Normal approximation	1/2	55,457	49,325 – 61,590	5.6
Bootstrap (uncorrected)	1/2	56,533	50,431 – 64,115	6.2
Bootstrap (bias corrected)			49,443 – 62,081	5.1
Normal approximation	1/2 + 5/6	57,498	51,647 – 63,349	5.2
Bootstrap (uncorrected)	1/2 + 5/6	57,900	52,426 – 64,348	5.3
Bootstrap (bias corrected)			53,543 – 63,891	4.6

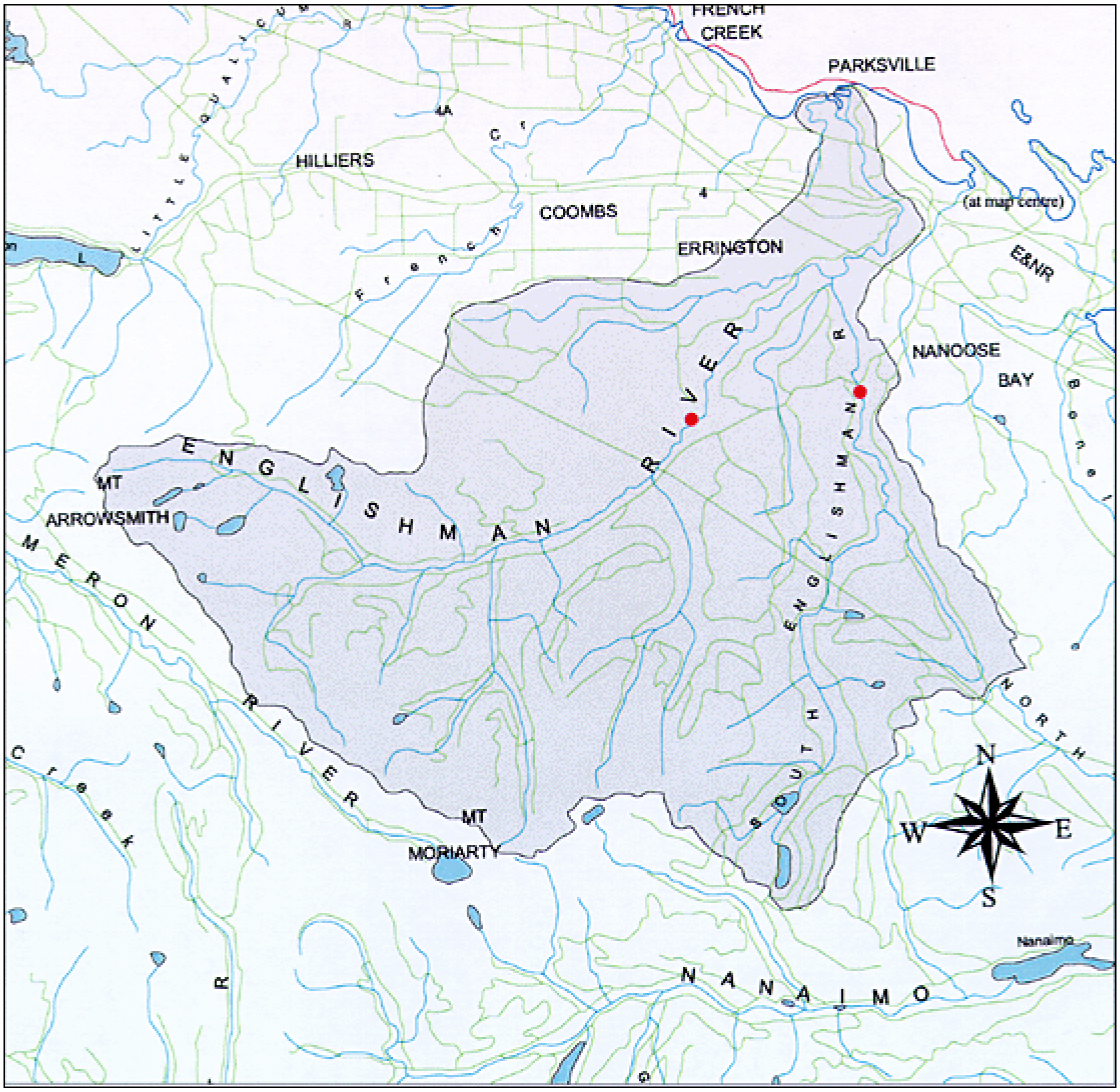

Figure 1. Map of the Englishman River watershed. Anadromous barriers are shown as red dots.

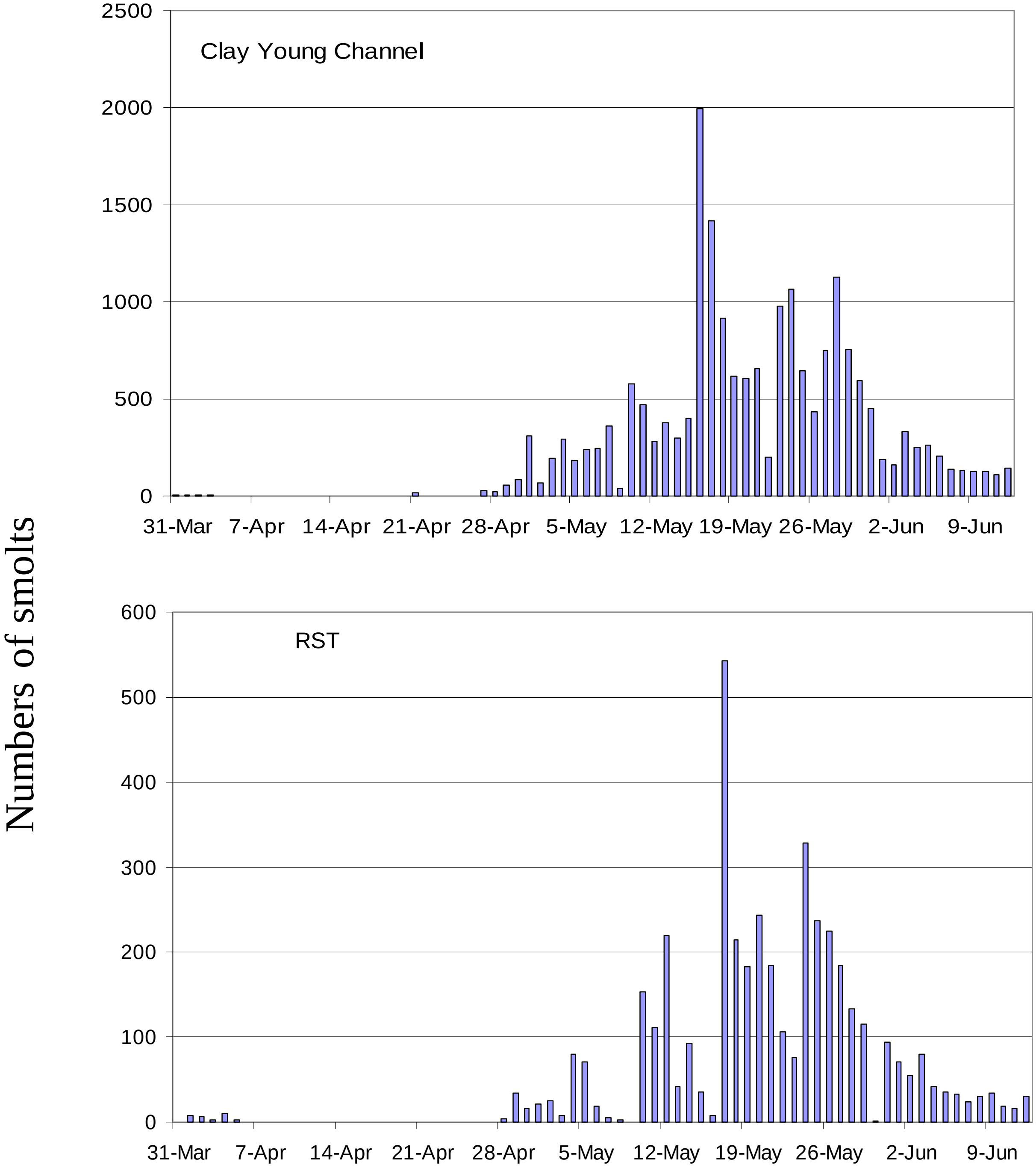

Figure 2. Daily catches of coho smolts from Clay Young Channel and in the rotary screw trap.

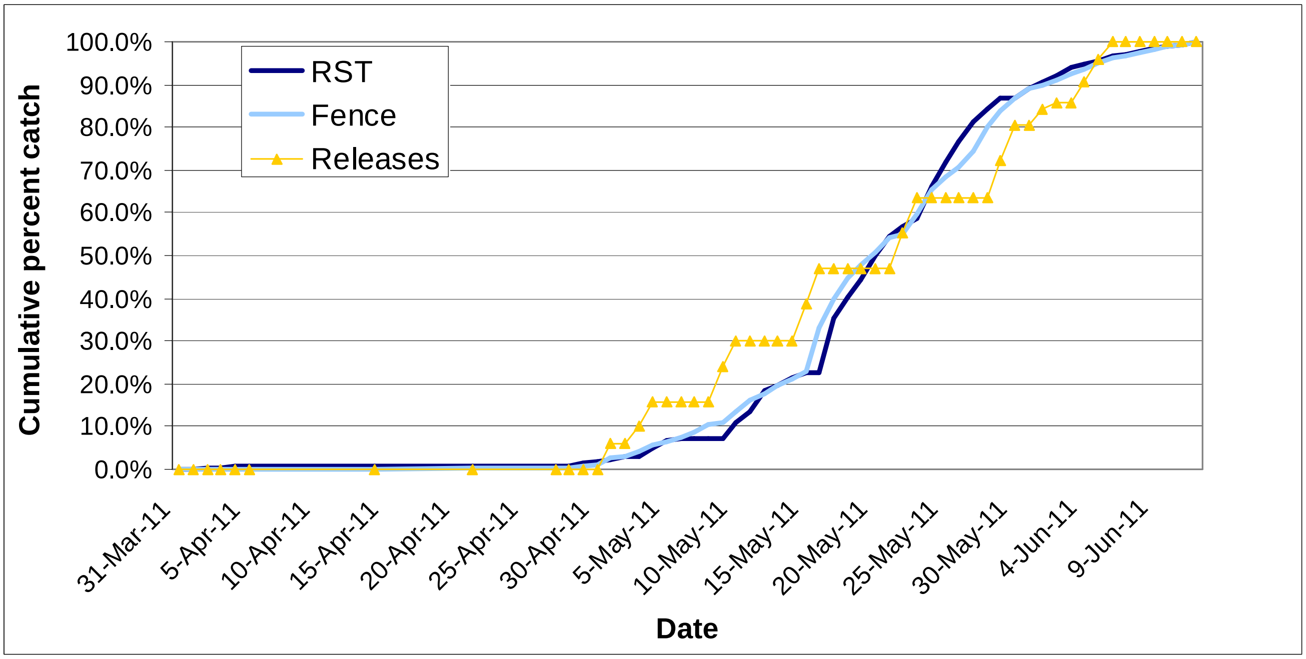

Fig. 3. Comparison of cumulative frequency distribution plots of RST catches, marked releases and unmarked coho smolts released at the fence.

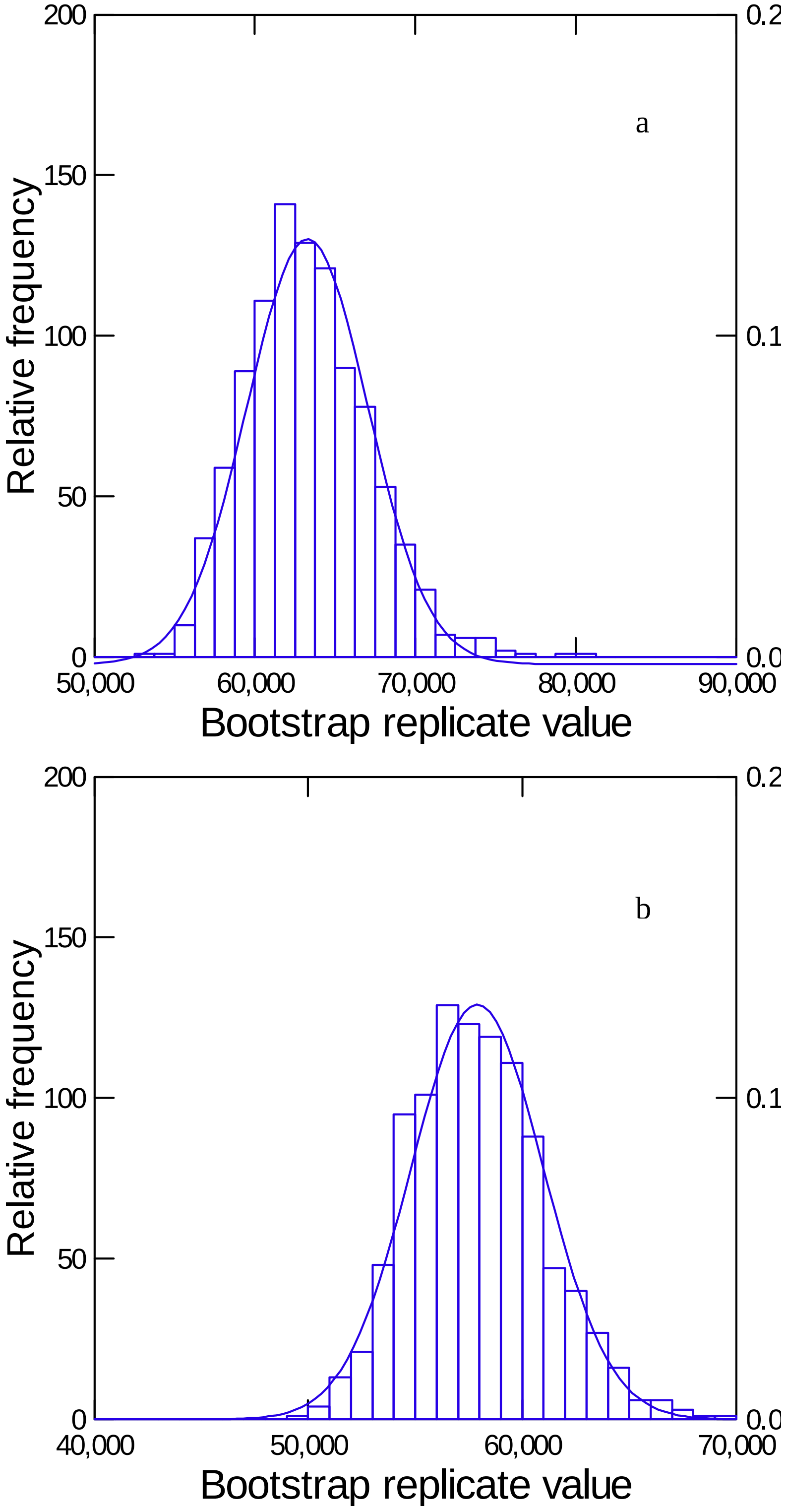

Figure 4. Frequency distribution of population estimates a) from the original data and b) from combined capture periods, from a parametric bootstrap procedure involving 1,000 iterations. The superimposed normal curve illustrates the degree of skewness.

Appendix 1. Total daily catch of coho smolts at the fence and in the RST, and releases by date from Clay Young Channel.

Date	Channel Catch	Marks released	RST Catch
31-Mar			6
01-Apr	7		6
02-Apr	6		6
03-Apr	2		4
04-Apr	10		0
05-Apr	2		1
14-Apr			2
21-Apr			15
27-Apr			29
28-Apr	4		20
29-Apr	34		58
30-Apr	16		83
01-May	21	294	310
02-May	26		67
03-May	7	186	195
04-May	80	268	297
05-May	71		182
06-May	19		237
07-May	5		244
08-May	2		359
09-May	0	400	41
10-May	154	300	576
11-May	112		472
12-May	220		284
13-May	42		379
14-May	92		300
15-May	36	400	400
16-May	7	400	1993
17-May	543		1417
18-May	215		915
19-May	183		616
20-May	243		604
21-May	184		658
22-May	106	400	200
23-May	76	400	976
24-May	328		1069
25-May	237		642
26-May	224		434
27-May	184		750
28-May	133		1130
29-May	116	400	755
30-May	1	400	596
31-May	94		450
01-Jun	71	188	188
02-Jun	55	62	161
03-Jun	80		336
04-Jun	42	236	248
05-Jun	36	263	263
06-Jun	33	191	206

07-Jun	24	137

Appendix 1. cont'd

08-Jun	31	136
09-Jun	34	126
10-Jun	19	129
11-Jun	16	110
12-Jun	30	142

Appendix 2. Daily catches of steelhead salmon, with selected fork lengths, and trout species at the Clay Young channel and in the RST.

	Fence				RST			
Date	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat
Mar-31	1							
Apr-01	4				3			1
Apr-02	1				5			
Apr-03					1			
Apr-04	1			1	2			
Apr-05	4				3			
Apr-14	4							
Apr-20	6							
Apr-26								
Apr-27	5							
Apr-28	0							2
Apr-29	9			1	18			
Apr-30	6	6		1	13	17		
May-01	13	5	179		15	8	232	
			183				175	
			200				150	
			170				155	
			147				154	
							182	
							164	
							148	
May-02	8	2		1	9	3	204	
							155	
							161	
May-03	11	1	184		4			
May-04	14	5	176	11	12	11	133	
			172				145	
			178				164	
			165				162	
			165				146	
							191	
							196	
							146	
							172	
							170	
							209	
May-05	5	2	168	1	13	8	172	
			176				160	
							150	
							165	
							151	
							160	
							145	
							145	
May-06	3	2	175	1	5	1	161	
			152					

Appendix 2. cont'd

	Fence				**RST**			
Date	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat
May-07	6	2	140					
			206					
May-08	6	6	170					
			180					
			189					
			144					
			131					
			205					
May-09	1	3	168	4				
			170					
			180					
May-10		9	255	2	10	7	145	
			255				159	
			256				177	
			176				150	
			180				182	
			165				205	
			191				182	
			185					
			166					
May-11	5				12	3	156	
							172	
							155	
May-12	3	2	184		22	14	159	
			160				144	
							165	
							168	
							158	
							170	
							196	
							136	
							180	
							155	
							144	
							154	
							156	
							158	
May-13	2	6	130			1	149	
			150					
			147					
			188					
			185					
			182					
May-14					3	6	147	
							158	
							148	
							140	
							168	
							150	

Appendix 2. cont'd

	Fence				**RST**			
Date	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat
May-15		4	190		4	2	166	
			169				137	
			178					
			170					
May-16	7	20	164	5				
			179					
			182					
			148					
			182					
			182					
			183					
			192					
			168					
			185					
			159					
			180					
			185					
			155					
			244					
			180					
			216					
			155					
			164					
			174					
May-17	2	4	156	2	15	27	151	
			179				149	
			200				190	
			181				180	
							147	
							171	
							150	
							152	
							153	
							151	
							152	
							187	
							176	
							288	
							174	
							191	
							169	
							167	
							186	
							152	
							154	
							185	
							172	
							165	

Appendix 2. cont'd

	Fence				**RST**			
Date	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat
							166	
							141	
							200	
May-18	1			1	15	4	156	
							162	
							135	
							182	
May-19		2	108		9	4	138	
			155				166	
							189	
							172	
May-20		6	198	1	10	8	168	
			168				175	
			208				168	
			110				136	
							147	
							112	
							145	
							245	
May-21	2	2	115	1	18	17	132	1
			184				148	
							155	
							162	
							160	
							145	
							155	
							185	
							137	
							181	
							163	
							150	
							152	
							176	
							140	
							175	
							155	
May-22	1	1	180	1	13	9	171	
							143	
							158	
							149	
							140	
							122	
							165	
							123	
							152	
May-23	3				1	3	149	
							159	
							143	

Appendix 2. cont’d

	Fence				**RST**			
Date	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat
May-24	1	2	189	2		14	190	
			185				145	
							125	
							150	
							142	
							157	
							163	
							148	
							185	
							158	
							135	
							150	
							130	
							155	
May-25		1	147		4	6	151	
							168	
							135	
							151	
							149	
							160	
May-26		5	150		4	19	145	1 DV
			170				152	
			186				185	
			110				155	
			114				150	
							160	
							172	
							148	
							175	
							160	
							145	
							140	
							160	
							136	
							170	
							205	
							147	
							190	
							129	
May-27		14	205	3		7	155	
			195				152	
			193				145	
			192				166	
			212				154	
			182				155	
			189				150	
			175					
			210					
			205					
			162					
			185					

195

Appendix 2. cont'd

	Fence				**RST**			
Date	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat	Rainbow	Rainbow /steelhead	ST lg (mm)	Cutthroat
			178					
May-28		9	209		4	6	165	1 DV
			169				136	
			177				152	
			150				158	
			235				164	
			175				172	
			215					
			184					
May-29	2	1	168	2	5	6	156	1
							162	
							155	
							175	
							170	
							149	
May-30	2	2	170		1			
			150					
May-31					7	3	158	
							169	
							169	
Jun-01	1				4	3	155	
							151	
							138	
Jun-02	1	1	185		5	2	120	1
							140	
Jun-03					6	9	135	
							151	
							153	
							132	
							144	
							165	
							134	
							142	
							142	
Jun-04				2	5	1	115	
Jun-05	1	2	132		6	1	147	
			188					
Jun-06				1	2			
Jun-07	1				2	1	144	
Jun-08					8			1
Jun-09					10	1	166	
Jun-10		1			4			
Jun-11		3	213	2	4			
			172					
			208					
Jun-12						1	145	
Totals	143	131		46	316	233		7
Mean Lengths			177.2				159.0	

Appendix 3. Daily water temperatures (^{0}C) at the Clay Young channel and the RST site.

Date	Clay Young channel	Mainstem RST
Mar-31		6.75
Apr-1	5	7
Apr-2	5	5.5
Apr-3	4.2	5
Apr-4	5	5.5
Apr-5	5	5
Apr-13		5
Apr-20		7
Apr-21		6.5
Apr-26		6.5
Apr-27		7
Apr-27	6	
Apr-28	6	6
Apr-29	6	6
Apr-30	6.5	7
May-1	7.5	7
May-2		8.5
May-3	7	
May 4	7	7
May-5	7.5	8.5
May-6	5.5	9
May-7	7	8.5
May-8	6	8
May-9		9.5
May-10	7	9
May-11	6.5	9
May-12	5	8
May-13	6	8
May-14	7	8.5
May-15	7	9
May-16	6	9
May-17	6	9
May-18	6	8.5
May-19	6	9
May-20	7	9.5
May-21	7	10.5
May-22	7.5	9.5
May-23	7	9.5
May-24	7.5	10
May-25	7	9.5
May-26	7	9.5
May-27	6.5	9
May-28	6.5	9
May-29	7.5	10.5
May-30	7.5	10.5
May-31	7.25	9.5
June-1	7.5	10.5
June-2	7	9.5
June-3	7	9.5

Appendix 3. cont'd

Date	Clay Young channel	Mainstem RST
June-4	7.5	11
June-5	8	11.5
June-6	8	12
June-7	7	11
June-8	8	11
June-9	8	11
June-10	8	11
June 11	8	10.5
June-12	8.5	10.5