Assessment of the contribution of off-channel habitat to the production of coho in the Englishman River

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ABSTRACT

The current program contributes to a series of studies that has assessed the overall coho smolt production in the Englishman River and quantified the portion originating in constructed and natural off-channel habitats. The 2010 program examined the proportion of smolts that derived from the Clay Young channel through a mark-recapture program, conducted between 12 April and 5 June. Overall emigration from the Englishman system, during the study, was estimated to be 42,038 ± 8,350 smolts, of which 43% were contributed by the constructed channel. Failure to initiate sampling during the early portion of smolt migration resulted in underestimation of the size of the outmigration. Interpolation of this period, based on migration timing in the previous year, suggests that this likely represented at least 5% of the total production. A parametric bootstrap estimate indicated that the outmigration was larger (44,312) than estimated and showed that the confidence intervals were less precise (range 36,073 – 62,994 smolts) than those based on the normal approximation. The large contribution to overall migration made by smolts from the Clay Young channel matched that found in 2009, which was the previous largest recorded proportion (41%) in any year of the program.

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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 2010 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 current design mirrored that of the 2009 study by utilizing 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 *(O. kisutch)* and chum *(Oncorhynchus 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 1,380 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 in 1989, primarily to create summer and winter rearing habitat for juvenile coho. The initial constructed length was 600 m: overall length was extended in 1998 and 2 spur channels were added for an overall wetted area of 6,000 m^2. 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 originating in the newly named Clay Young channel. This 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}.

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 2009 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). Since a large number of smolts were expected to be available from Clay Young Channel, similar to that found in 2009, smolts numbers were not anticipated to be a limiting factor in any but the initial and final strata. Consequently, the total relative error (r_h) was set at ±15% for 95% precision and the calculated number of marks required to achieve this target was considered to be a minimum for the program.

Strata totals from the 2009 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 2010, given a provisional program duration of April 17 to June 7. These were 3%, 16%, 29%, 40% and 12%. The 2009 capture efficiency of 6.7% was assumed for the RST, although this was higher than in earlier studies. 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 28% 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 α=0.05 from data given in Carlson et al. (1998). Solution of equation 2 indicates that the release of 781 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 – 135mm), 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 12 April to 5 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 and steelhead 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. Scale samples were taken from 8% of the juvenile steelhead captured at the fence and provided to the BC Ministry of Environment for age analyses. Water temperatures were collected daily at each weir and at the RST locations (Appendix 3).

Marking and subsequent release of smolts collected at the weirs was performed to estimate overall population size of the Englishman River outmigration from collections of marked and unmarked smolts from the lower river. All juvenile coho > 65 mm were considered to be smolts. 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.

2.2.4 Mainstem sampling

A rotary screw trap (RST), 2 m in diameter, 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 2009 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 12 April. Low numbers of smolts (<50 per day) were encountered until 10 May and it was assumed that migration timing was delayed by cool weather. However, while over the period 12 - 30 April average water temperature in the channel was 8.0^{0}C, compared with 9.5^{0}C in 2005 (Taylor 2005), this was slightly warmer than the same period in 2009 (7.4^{0}C, Taylor and Wright 2010). During the study, water temperature in the side-channel ranged from 6^{0}C to 11.5^{0}C, while the mainstem reached a slightly lower maximum temperature (11^{0}C).

The reason for the delayed migration of smolts from the channel may have been related to beaver activity. A beaver dam was broken open by the field staff on 9thMay and shortly after the numbers of smolts encountered at the fence increased from less than 50 on average, to more than 1,000 (Fig. 2). It seems likely that these events were related and that early movement of smolts in the mainstem may have been uncorrelated with the fence output (see below). Subsequent opening up of beaver ponds were accompanied by an increase in smolt numbers from 265 on 25 May to 861 by 27 May.

Daily smolt migration is illustrated in Fig. 2. Peak migration occurred on May 23, with a count of 3,014 smolts: 65% of the total migration from the channel (11,676 smolts) was recorded over a ten day period between May 11 and 20 (Appendix 1). A total of 3,270 smolts were marked for population estimation: releases by mark type and period are provided in Appendix 1.

The total count of juvenile coho from the Clay Young Channel was 18,044 individuals: on the last day of sampling 188 were captured, indicating that the outmigration was incomplete and that this total is an underestimate of channel production. While this density of smolts is high (approximately 4,400 km^{-1}), and exceeds the range of estimates provided by Marshall and Britton (1990) for coastal streams (1990: 363 – 3018 km^{-1}) it is only 51% of the 2009 total. Adjusted for unsampled length, the estimate from the Clay Young channel is 18,531 smolts, or 4,520 $smolts.km^{-1}$. This falls below the 5,451 $smolts.km^{-1}$ recorded from the Nature Trust Channel in 1998 (Decker et al. 2003) but compares well with the 2004 density of 4,270 km^{-1} (Taylor 2005).

Totals of 410 upper caudal, 238 anal, 511 and 141 lower caudal marked smolts were measured during the program. Mean fork lengths for these groups is given in Table 1, the mean for all mark types was 102.7 mm (SD 15.0).

3.2 Mainstem sampling

Over the course of the program, the mainstem RST captured 4,830 individuals, of which 421 smolts were recaptures. Unfortunately, under the assumption that low numbers of smolts originating from the channel in the early part of the program informed the mainstem movement, the RST was not fished until 11th May. This resulted in an unknown portion of the outmigration being missed (Fig. 2a) and biased the initial stratum estimate by over-representing the proportion of marks. The stratum estimates of population size and associated statistics derived from the combinations of catches and recaptures are presented in Table 1.

Capture probabilities for the RST averaged 11.2 % (Table 2), and demonstrated significant temporal variation (Pearson chi-square, $\chi 2 = 269.7$, df = 3, $p < 0.001$). The range of values was 1.2% to 18.5%, the last being the highest rate found in any study to date. The very low value recorded in the last stratum, had no obvious explanation although re-adjustment of the RST to fish in lower water levels may have contributed to lower catches on some dates. As a result of the high variability, 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. Instead, the individual period estimates were summed to provide an overall population estimate for the Englishman system.

The estimate of total smolt numbers was 42,038 (95% CI 33,688 – 50,387). Precision for this estimate (± 10.1 %) was 1/3 greater than the design target and, overall, was biased upward by the low recapture probability in the final stratum, which realized a coefficient of variation of 36.8% (Table 2a). The excellent precision found in the other strata derived from the much higher than predicted capture probabilities, in conjunction with the larger than required release of marks from the channel (844 -1000 versus ~780 estimated to be needed on each occasion).

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 discrepancy between the movements of smolts from the channel prior to the RST becoming operational is shown by the separation of the curves. Adjustment to correct for the unsampled mainstem population is illustrated in Fig. 4, with interpolation loosely based on the 2009 outmigration rate. This assessment was performed purely to illustrate a possible lower bound to smolt movement during this period, as we have no information on the actual density of migrants on these dates. The substantial difference between migratory patterns in 2009 and 2010 (Fig. 4) suggests that movement was earlier in 2010 and the initial portion of the migration could have been larger than illustrated by the interpolated data. Using the additional number of smolts (380) estimated to have moved downstream in stratum 1 as a minimum, these fish would have elevated the stratum estimate to 16,339 (± 2,047): stratum precision was unchanged at 6.4% (Table 2b). The total population estimate would then be at least 44,083 (95% CI 35,672 – 52,493 Table 2b) an increase of 4.9%. The proposed larger catch in the first stratum resulted in a slight increase in overall precision to ± 9.7 %.

Given the wide range in capture probabilities, the degree of precision achieved overall and over the initial 3 strata, was examined using a parametric bootstrap technique (Carlson et al. 1998). Table 3 indicates that for the 4 strata combined, there was a substantial difference between the bootstrap confidence range and that calculated using the normal approximation. The bootstrap data show a significant departure from normality (Shapiro-Wilk statistic 0.695 $p < 0.001$) and hence shift in the confidence bounds as a result of the non-symmetrical distribution (Fig. 5). The influence of the poor capture probability in the final stratum resulted in loss of precision (CV 16.0% compared to 10.1%) and exaggeration of the bounds around the estimate: the standard error almost doubled, from 4,260 to 8,031 in the bootstrap estimate. The estimate of outmigration is very close to the adjusted estimate for the unsampled early migrants, described above (44,083), and points to an underestimate of population size. After accounting for the small amount of bias, the actual loss of precision is still very high (CV 15.5%) almost exclusively due to the degree of variation introduced by the final sampling period. This can be seen in Figure 5, and confirmed by comparing the population estimate from only the first 3 strata. These estimates were very similar (31,149 versus 31,305 Table 3) with only a small increase shown by the bootstrapping. The 95% confidence intervals were also very similar and the degree of precision in all estimates was equal (CV 4.7%).

3.3 Sources of bias in the population estimate

There were two potential sources of bias in the 2010 program. The first and less serious resulted from failing to sample the initial portion of the outmigration. The second was poor catchability in the final stratum. This was of indeterminate origin, but resulted in a substantial loss of precision: bootstrapping suggests that recovery of marks diverged significantly from the underlying hypergeometric distribution and that precision was poorer than indicated by the normal approximation. The confidence intervals are also markedly different, due to the non-symmetrical distribution of the bootstrapped estimates (Fig. 5). However, the confidence interval for the overall series of strata indicates that bias in the estimate was low: the bias corrected 95% CI differed by less than 3% from the uncorrected bounds.

The assumptions that are required to be fulfilled for the unbiased estimation of population size using a Petersen estimator have been dealt with in detail by a number of authors e.g. Seber (1982), Arnason et al. (1996). They are examined here briefly, in conjunction with assessment of compliance in the present study.

I. No mark loss – the primary issue here is short term mortality effects i.e. between release and recapture, although reporting of marks can influence the estimate, particularly if marks are indistinct or susceptible to removal. Marking mortality was assessed during the program, and was found to be inconsequential.

II. Population closure – Closure has different implications for stratified versus non-stratified designs. For this project, it requires that all of the population is encompassed within the sampling period. At the conclusion of the project only a small number of smolts were still being caught in the RST, however in excess of 100 smolts were moving out of the Clay Young channel daily. 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 the underestimate of population size.

III. All smolts share the same probability of capture, or, an equal probability of being examined for marks. 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. 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 the second and fourth marking periods (Pearson $\chi 2 = 10.07$, df = 5, p = 0.07, $\chi 2 = 3.59$, df = 5, p = 0.61), but not in the first and third (Pearson $\chi 2 = 16.39$, df = 6, p = 0.01, $\chi 2 =$

15.74, df = 6, p = 0.02). In the first period marked fish tended to be larger than the average unmarked smolt, but smaller in the third. There was very close agreement between the distributions of fork lengths of marked and unmarked smolts collected in the RST. However, a goodness of fit test on recaptured versus not recaptured smolts showed significant size selectivity by the trap (Pearson $\chi 2$ = 20.96, df = 6, p = 0.002), likely as a function of the high power (> 0.999) of the test (Carlson et al. 1998) given the large numbers of measurements (n= 1,221). In any event, increased catchability of a segment of the migration does not necessarily produce bias in the stratum estimates. Since the marked releases constitute a random sample, the recovery sample can be selective as long as this is independent of mark status (Seber 1982). Examination of the overall size distribution of recaptured smolts suggested that these were larger (FL 99.2 mm) than the mainstem smolts (FL 96.1 mm) but smaller than the overall population of marks (FL 102.7 mm). Since RSTs tend to select for smaller fish that have lesser avoidance abilities the smaller average size of marked recaptures is not unexpected.

IV. Constant probability of capture – ideally, catchability should remain stable throughout the study although most capture gear displays size selectivity (Ricker 1975). A particularly important source of uncertainty is the variation in capture probability over time, which can be exacerbated by the potential for smolts to move in schools, as opposed to moving independently. This may result in greater than expected variation in capture probabilities (overdispersion) and increased bias. Temporal stratification, as employed in the present study, can minimize bias by compensating for events, such as fluctuations in discharge, however, capture probability was depressed in the last stages of the outmigration. The resulting variability reduced the overall precision of the estimate, although the degree to which this factor biased the overall estimate appears to be low.

V. 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 and was not an issue in this study. The low numbers of marks collected in the final stratum (30 May – 5 June) suggest that some portion of the final mark releases may not have had the opportunity of being sampled in RST catches. We feel that this was unlikely, however, since the time of travel of fish from the various release sites to the recapture sites is less than the stratum duration, and all captures were completed within 3 to 4 days in each stratum.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The estimate of smolt abundance (42,038 ± 8,350 coho) suffers from a number of intrinsic and potential sources of bias, as reported above, not the least of which is the failure to represent total emigration. Some of these resulted from errors in execution of the program (failure to sample the early migrants, premature conclusion of sampling at the Clay Young channel) while another potentially occurred as a function of the sampling methodology (reduced capture probability in the final sampling period). The latter was responsible for loss of precision in the estimate and the confidence bounds may be conservative due to the skewness displayed by the bootstrap distribution. This was particularly disappointing, given the capture rates in the main body of the program (average 14.6%), which were higher than in any previous study. However, although the program produced an underestimate of smolt abundance, 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. There was fairly good agreement among the rates of migration illustrated for the channel and mainstem although the former lagged behind the overall migration, possibly due to the blocking effect of beaver dams (Fig. 3). Clearly, there is agreement between the current estimate of side-channel contribution and that estimated in the previous year of the study (Taylor and Wright 2010), that suggests that the Clay Young side-channel provides a much larger contribution to the smolt output (43%) than would be expected on the basis of channel length (8% of the system length). However, this proportion represents some degree of overestimate for the 2010 outmigration.

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 (Fig. 6). Since the 2010 estimate is an underestimate, the actual migration size is very likely to lie somewhere between that of the previous year and the calculated value. However, it is highly probable that the true value is closer to the calculated estimate than the very large migration found in 2009 (95% CI 78,241- 92,692). Given the degree of discrepancy, at least one additional study will be required to describe the degree of variation in the overall smolt output from the system and the contribution from the Clay Young channel.

The principal recommendation for future programs is to ensure that scheduling of the sampling periods encompasses smolt migration timing. It is important that sampling in the mainstem should commence concurrently with that in the channel, even if catches in the latter are low. Mark releases do not have to occur at the beginning of a sampling period as long as there is some expectation of consistency in capture probabilities. It is also important to ensure that the conclusion of emigration is represented in catches to reduce potential bias resulting from inaccurate capture efficiency.

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Table 1. Summary of coho smolt fork length (mm) by mark type measured at the Clay Young Channel and from the RST captures. Mark types correspond to marking strata, with upper caudal marks released in periods 1, 3 and 5.

Site	Mark	n	mean FL	min FL	max FL	SD
Clay Young	UC[1]	410	106.9	74	141	15.8
	A[2]	163	102.7	78	142	14.2
	LC[3]	141	96.2	75	123	11.9
	A[4]	75	97.8	76	128	13.1
	All marks	799	102.7	74	142	15.0
RST	UC	182	101.7	74	127	12.0
	A	119	97.1	76	137	11.2
	LC	119	96.3	70	125	10.8
	NM[5]	581	96.4	71	147	13.2
	All marks	420	98.7	70	137	11.6
	All smolts	1001	97.3	71	147	12.6

[1] UC = upper caudal fin, [2] A = anal fin, [3] LC = lower caudal, [4] A = anal fin second application period, [5] NM = no mark

Table 2. Estimates of population size derived from recovery sampling by the rotary screw trap a) excluding the early outmigrants that were not sampled by the RST, b) including an interpolated estimate of number of outmigrants prior to commencement of sampling. 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
11-May-10	2655	1000	185	14294	16077	12511	6.4	18.5%
18-May-10	1473	1000	113	12943	15082	10804	8.4	11.3%
23-May-10	550	844	118	3913	4487	3338	7.5	14.0%
30-May-10	152	426	5	10889	18739	3038	36.8	1.2%
Total	4830	3270	421	**42,038**	**50,387**	**33,688**	10.1	11.2%

b)

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	upper 95% CL	lower 95% CL	CV	capture probability
11-May	3019	1000	185	16253	18289	14217	6.4	18.5%
18-May	1473	1000	113	12943	15082	10804	8.4	11.3%
23-May	550	844	118	3913	4487	3338	7.5	14.0%
30-May	152	426	5	10889	18739	3038	36.8	1.2%
Total	5210	3270	421	**44,083**	**52,493**	**35,672**	9.7	11.2%

Table 3. Comparison of levels of precision obtained form all temporal strata and from only the first three 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	Estimate	95% C I	CV
Normal approximation	All	42,038	33,688 – 50,387	10.1
Bootstrap (uncorrected)	All	44,312	36,375 – 64,089	16.0
Bootstrap (bias corrected)			36,073 – 62,994	15.5
Normal approximation	1 - 3	31,149	28,306 – 33,992	4.7
Bootstrap (uncorrected)	1 - 3	31,305	28,628 – 34,399	4.7
Bootstrap (bias corrected)			28,628 – 34,399	4.7

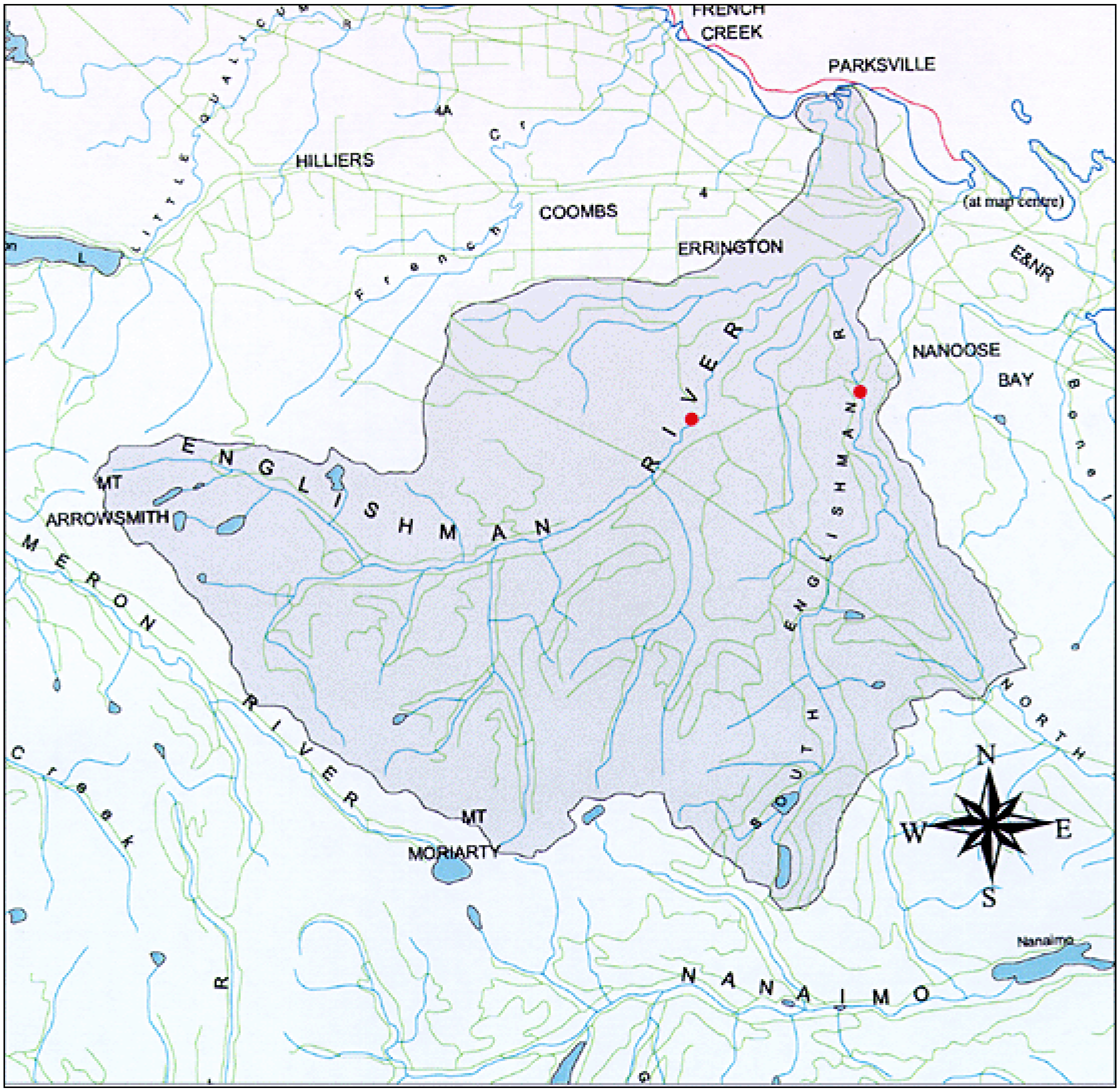

Figure 1. Map of the Englishman River watershed. Anadromous barriers are shown as red dots.

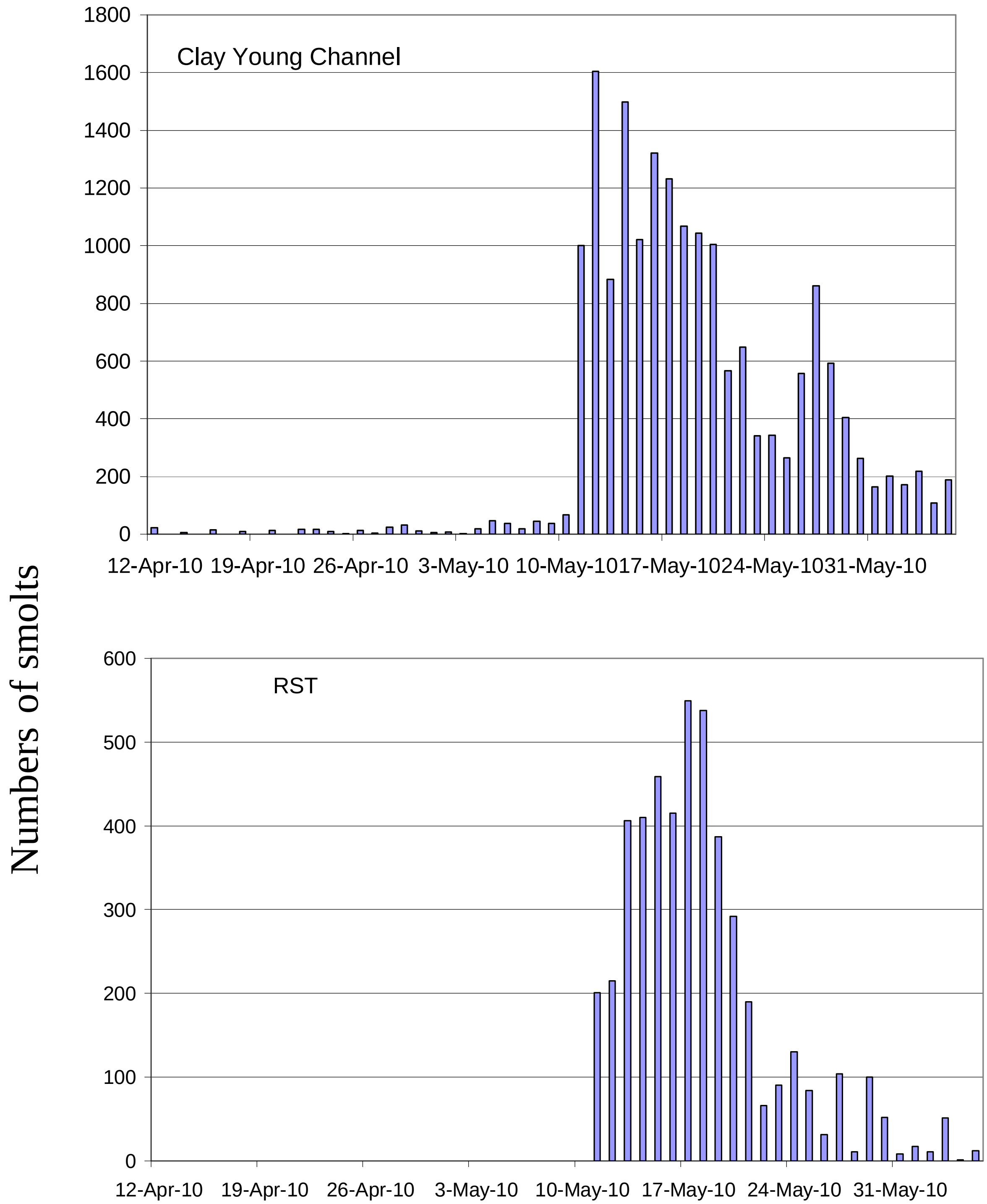

Figure 2. Daily catches from Clay Young Channel and in the rotary screw trap.

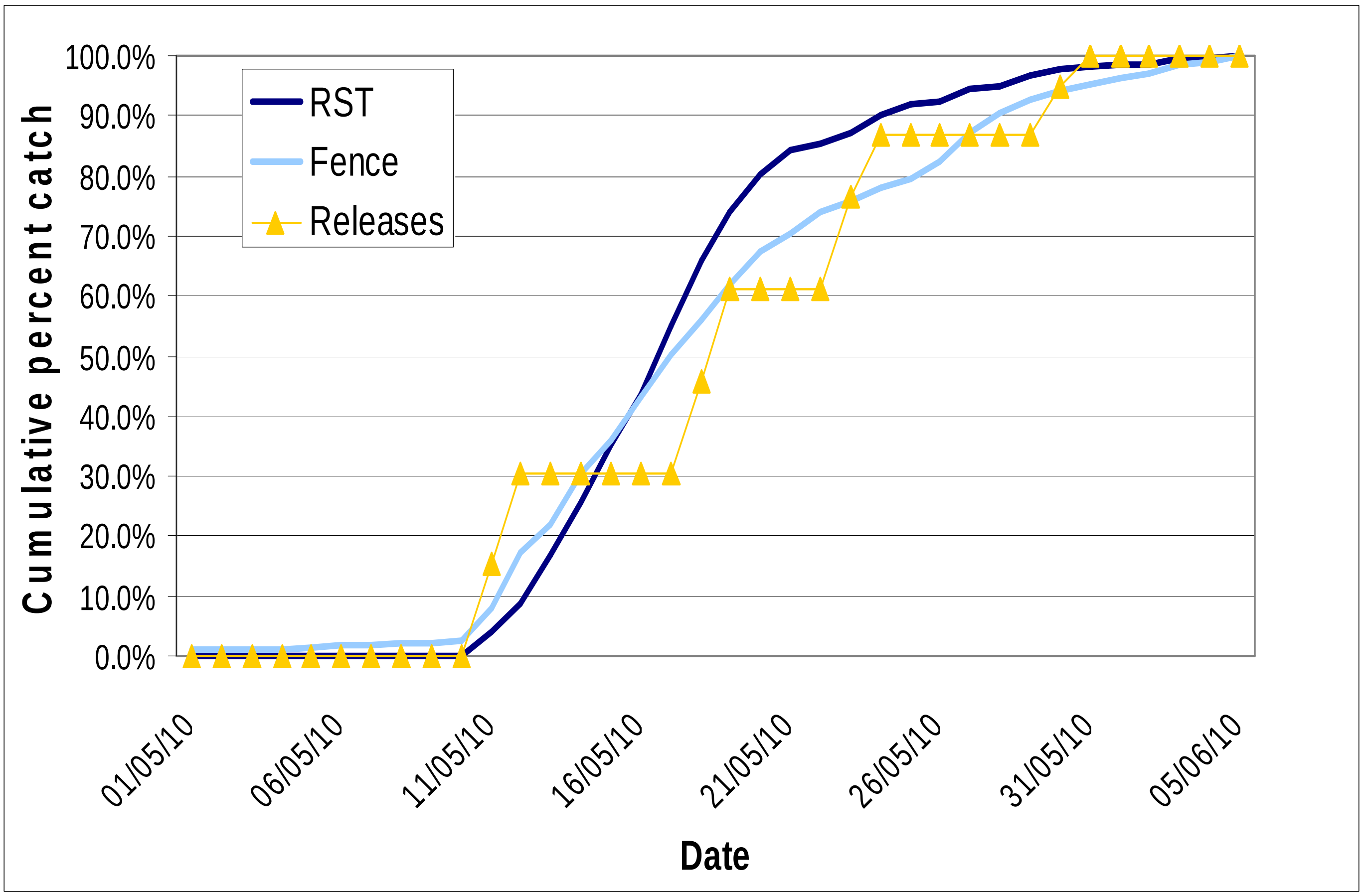

Fig. 3. Comparison of cumulative frequency distribution plots of RST catches, marked releases and unmarked smolts released at the fence.

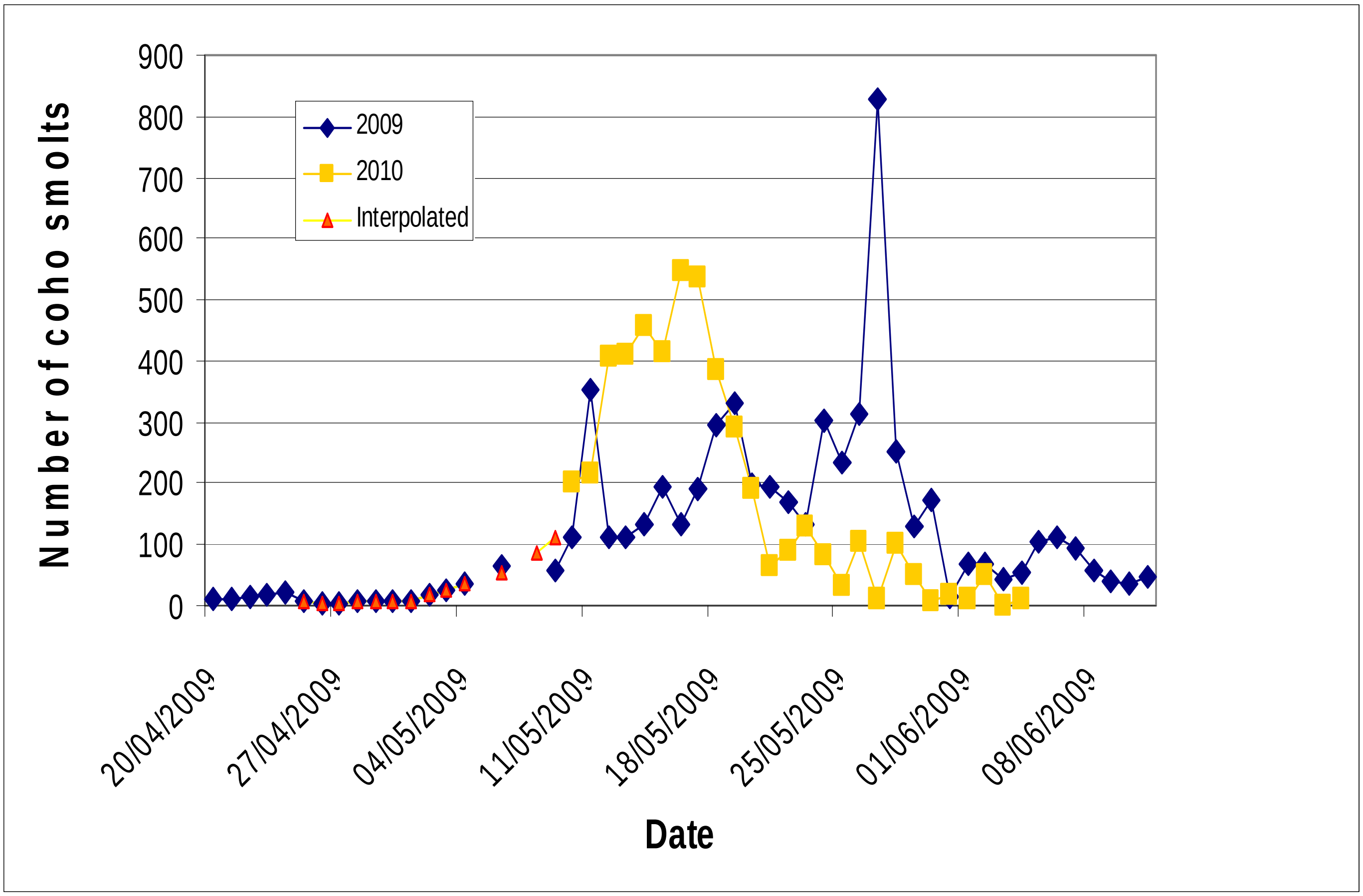

Figure 4. Comparison of daily RST catches of coho smolts in 2009 and 2010. Interpolation to provide a minimum catch estimate over the unsampled period in 2010 is shown.

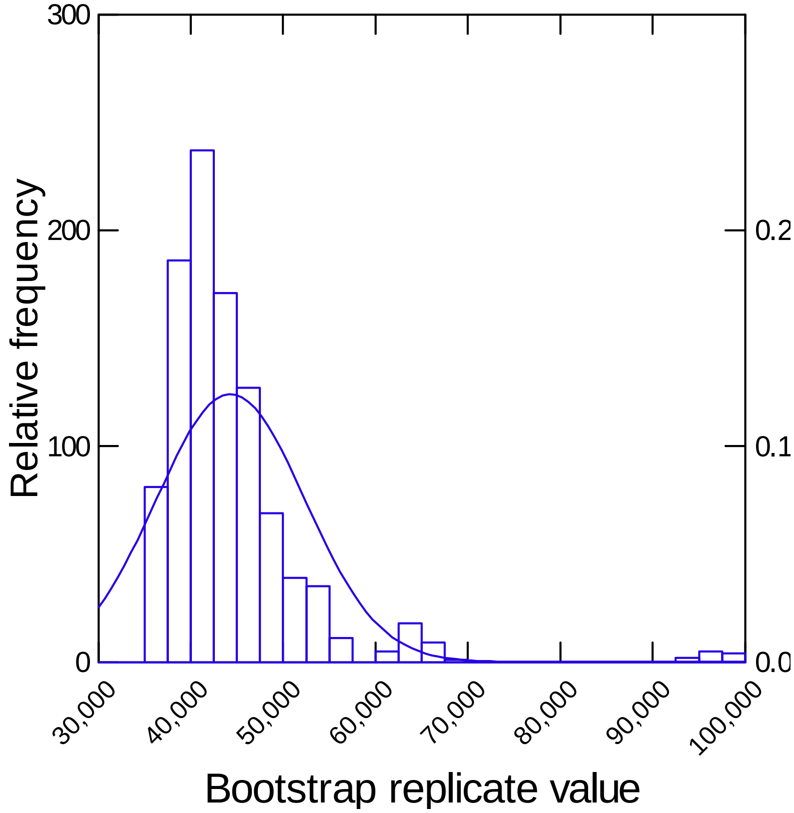

Figure 5. Frequency distribution of population estimates from a parametric bootstrap procedure involving 1,000 iterations. The superimposed normal curve illustrates the degree of skewness. The effect of high variability in capture probabilities in the fourth stratum is illustrated by the extremes in the right tail of the histogram.

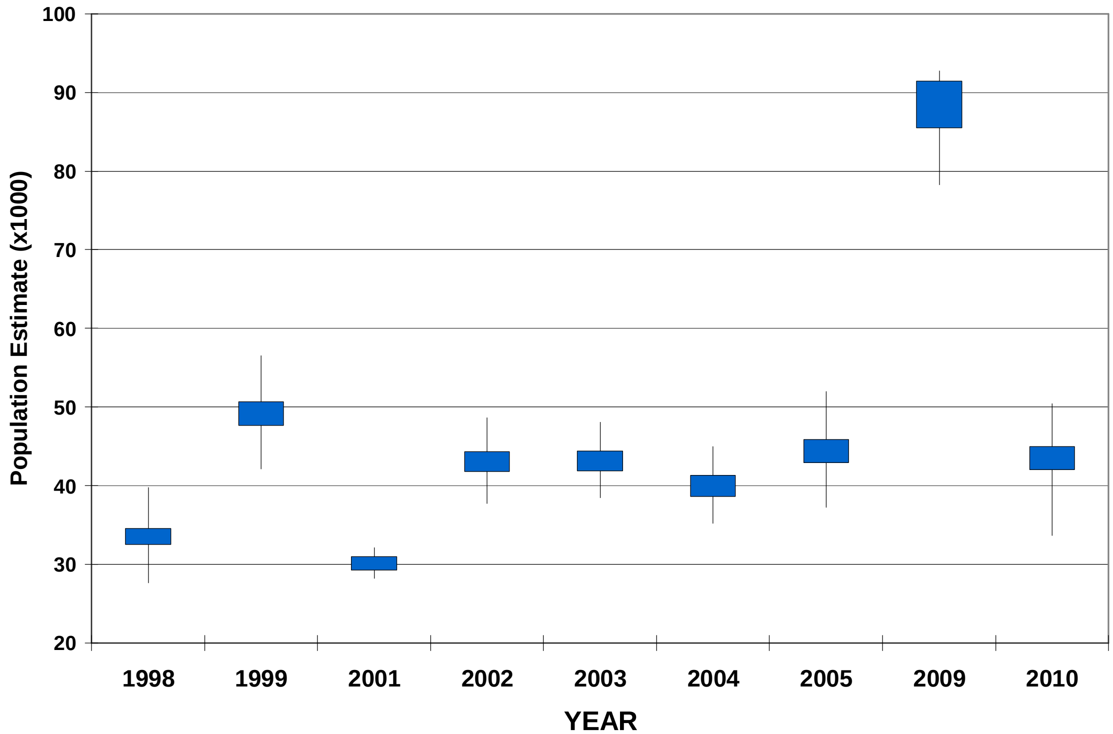

Figure 6. Comparison of annual estimates of smolt production in the Englishman River. The vertical height of the boxes represents the estimates adjusted for that portion of the river downstream of the sampling location although this correction is not performed in current studies.

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
12-Apr	22		
14-Apr	5		
16-Apr	15		
18-Apr	9		
20-Apr	13		
22-Apr	16		
23-Apr	16		
24-Apr	9		
25-Apr	2		
26-Apr	12		
27-Apr	4		
28-Apr	25		
29-Apr	32		
30-Apr	10		
01-May	5		
02-May	7		
03-May	2		
04-May	19		
05-May	47		
06-May	37		
07-May	19		
08-May	44		
09-May	38		
10-May	67		
11-May	1000	500	201
12-May	1605	500	215
13-May	884		406
14-May	1497		410
15-May	1021		459
16-May	1321		415
17-May	1232		549
18-May	1068	500	538
19-May	1043	500	387
20-May	1005		292
21-May	567		190
22-May	648		66
23-May	342	500	90
24-May	344	344	130
25-May	265		84
26-May	556		31
27-May	861		104
28-May	593		11
29-May	404		100
30-May	263	263	52
31-May	163	163	8
01-Jun	201		17
02-Jun	171		11
03-Jun	219		51
04-Jun	108		1
05-Jun	188		12

Appendix 2. Daily catches of steelhead salmon and trout species at the Clay Young channel and RST.

Trout counts by day at the Fence and RST

Date	Fence		RST	
	Steelhead	Trout	Steelhead	Trout
12-Apr	5	2		
14-Apr	10	1		
16-Apr	4	2		
18-Apr	6			
20-Apr	15	8		
22-Apr	10	7		
23-Apr	3	2		
24-Apr	1			
25-Apr	0			
26-Apr	5	10		
27-Apr	5	8		
28-Apr	4	7		
29-Apr	1	2		
30-Apr	6	4		
1-May	4	3		
2-May	4	2		
3-May	1	2		
4-May	8	11		
5-May	2	4		
6-May	3	0		
7-May	1	2		
8-May	1	6		
9-May	4	4		
10-May	11	13		
11-May	10	17	37	12
12-May	26	27	34	11
13-May	33	28	45	15
14-May	9	35	30	20
15-May	0	8	25	22
16-May	1	9	13	16
17-May	2	21	10	15

Appendix 2. cont'd.

Date	Fence		RST	
	Steelhead	Trout	Steelhead	Trout
18-May	6	5	11	17
19-May	0	5	8	14
20-May	4	17	8	8
21-May	3	1	4	7
22-May	3	5	3	4
23-May	0	6	1	1
24-May	1	1	2	5
25-May	0	0	1	0
26-May	0	2	7	0
27-May	21	16	1	1
28-May	15	11	2	0
29-May	9	5	1	0
30-May	1	2	1	1
31-May	8	5	2	4
1-Jun	5	6	1	1
2-Jun	0	5	0	2
3-Jun	2	7	4	3
4-Jun	3	3	0	0
5-Jun	0	0	0	2

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

Date	Clay Young channel	Mainstem RST
12-Apr	6	
14-Apr	8	
16-Apr	8	
18-Apr	9	
20-Apr	9	
22-Apr	8	
23-Apr	7.5	
24-Apr	7.5	
25-Apr	7.5	
26-Apr	8	
27-Apr	9	
28-Apr	8	
29-Apr	8	
30-Apr	9	
01-May	9	
02-May	9	
03-May	8.5	
04-May	7.5	
05-May	7	
06-May	8	
07-May	7.5	7.5
08-May	8.5	9
09-May	9	9
10-May	10	10
11-May	10	11
12-May	10.5	9.5
13-May	9.5	10
14-May	11	9
15-May	11	9.5
16-May	11.5	10
17-May	11	10
18-May	11.5	9.5
19-May	11	8.5
20-May	9.5	7
21-May	9	8
22-May	9	10
23-May	9	9.5
24-May	9.5	9
25-May	10	9
26-May	10.5	9
27-May	10.5	9
28-May	11	9.5
29-May	10.5	10
30-May	9.5	9.5
31-May	10	9.5
01-Jun	10	9.5
02-Jun	11	10
03-Jun	10	10.5
04-Jun	10.5	9
05-Jun	10.5	10.5