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Assessment of the 2005 outmigration of juvenile coho from the Englishman River

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ABSTRACT

The 2005 coho smolt outmigration from the Englishman River, was assessed through a mark-recapture program conducted between April 21and June 6. Marked smolts were released from the Nature Trust Channel and from the first of two capture points in the lower river, where recoveries were made using rotary screw traps. Significant rainfall events in the latter part of the program potentially corresponded with peak smolt movement and degraded capture efficiency, resulting in a probable underestimate of the population. Estimates of population size from the two sites were very different, potentially due to variable within stratum capture probabilities for marks early in the program. The stratified estimate, using primary mark releases, from the lower trap (42,701, 95% CI 37,376 – 48,026) had greater accuracy (± 12.5%) than at the upper site (45,909, 95% CI 39,320- 54,498), although trap efficiency was lower (5.1% versus 8.2%). The former estimate had consistent capture probabilities among strata and was adopted as the best estimate of total smolt migration.

A complete count of coho migrants from the Nature Trust channel was made, totalling 3,695 individuals, adjusted to 3,954 to include unsampled channel. Smolt density (2,865 km^{-1}) was lower than in 2004, however, the continuing importance of the contribution (9.3%) of the Nature Trust channel to coho production in the Englishman system is evident.

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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). In order to address these deficiencies, 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 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. Previously, a number of population estimates of juvenile coho and other species rearing in the constructed channels were produced in the 1990's. However, these employed different methodologies and were difficult to compare directly (Miller 1997). Directed efforts to quantify the contribution of channel coho to the Englishman system, were made in series of projects initiated in 1998, using mark-recapture. From 2002, these studies were ratified by ERWRP and funded by PSEF. The present study reflects modification to the methods used in these programs, to concentrate on estimation of overall population size of coho smolts in the Englishman watershed, using the Nature Trust channel as the primary source of marks.

2.0 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 two 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. It provides 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 represent 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).

3.0 METHODS

In their simplest form, the design of studies initiated in 1998 enabled an estimate of total coho smolt population size from a simple Petersen mark-recapture estimator, using catch data from two rotary screw traps (RSTs) in the lower Englishman River (Decker at al. 2003). Marks were released in conjunction with enumeration of a substantial portion of the smolt outmigration from the Nature Trust and Weyerhaeuser side-channels and, from 2001 to 2004, from Centre Creek, a natural tributary. Permutations of the design have included stratification of mark releases by release site only (1999) and with the inclusion of temporal (release period) stratification, analysed with a pooled Petersen estimator (PPE) and the use of a maximum likelihood estimator after Plante (1990) and as used by Arnason et al. (1996) in their Stratified Population Analysis System software package (SPAS). Generally, a series of estimates of population size are obtained from geographical stratification (release and recovery combinations), and, in a majority of years, the population estimates have been obtained by pooling the temporal strata (release periods).

Contemporary programs suffered from the complexity inherent in stratified mark-recapture design and particularly in the case of the Englishman River design where mark application was performed at two channel locations and a tributary, followed by a recovery site (upper RST). The addition of discrete marks for each release period in 2004 necessitated a total of 12 different fin marks to be applied over 4 temporal and 3 geographical strata. This level of complexity resulted in duplicate mark types being released by the two field crews and one mark was applied in error over multiple strata. Additionally, the funding level for the 2004 program was insufficient to conduct sampling over the entirety of the migration resulting in an inevitable underestimate of the population. Consequently, there was some impetus to streamline the program design as well as to create greater efficiency in terms of manpower for the 2005 study.

The basic elements of previous programs were employed in 2005, with the release of marked smolts from a side-channel into the mainstem population to be subsequently recovered downstream and counted to estimate total abundance for a segment of the population. However, a modified design, based on the simple stratified M-R technique of Carlson et al. (1998) was adopted. The new design simplified marking protocol and simplified the resultant count of recoveries as well as reducing personnel costs. Only one channel release site was used (Nature Trust) and 2 mark types were alternated between release strata. Two additional mark types were alternated at the upper RST site. As a result, coho captured in the lower RST had to be examined for only 4 distinct marks.

3.1 2005 Study Design

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 2004 study was used to generate the necessary parameters to calculate the required sample size for mark releases per stratum.

3.1.1 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). However, the large number of smolts available from Nature Trust in 2004, suggested that smolts numbers would not be a limiting factor in all but the initial and final strata, and the total relative error (r_h) was set at ±15% for 95% precision.

Strata totals from the 2004 migration were used to estimate the proportion of the population encountered in each time period (ϕ_h) : a total of 7 strata were anticipated for 2005, given a provisional program duration of April 17 to June 17. These were 3%, 8%, 14%, 21%, 34%, 14% and 6%. A conservative capture efficiency of 10% was assumed for an RST, just less than the 11% recorded in 2004 and 12% in 2003. 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 30% 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). A minimum of 468 marked fish is then required for release in each stratum.

3.1.2 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:

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

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 $\chi 2$ goodness of fit test after Seber (1982: p74). Similarly, size selective catchability was tested by comparing the distributions for recaptured and not recaptured smolts ($\chi 2$ Seber 1982: p71).

3.1.3 Channel and tributary smolts

Coho smolts (all juvenile coho > 65 mm were considered to be smolts) were captured for marking at a converging downstream weir located 100m above the Nature Trust channel outlet: a description of the construction and operation of the weir is given by Decker et al. (2003). 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. Two distinct marks, chosen for maximum visibility, upper caudal and anal fin, were alternated throughout the study. Marking commenced as soon as the RSTs were installed and fishing. Provisional sampling periods were established before the study started and were adjusted as necessary to accommodate the minimum required mark releases and flow conditions in the mainstem. The weirs were operated from April 21 to June 6, with marking conducted for a variable number of days in each period, based on smolt abundance: total mark releases are provided in Appendix 1. The intent was for all marks released in each period to have moved through the system to the upper 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. On days when marking was not conducted, smolts were either held in a flow-through holding box or the weir was closed. This box was also 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.

Weir integrity was maintained from an early stage in coho migration, throughout the project until cessation of movement and, consequently, the total smolt count closely reflects population size for the channel. Total emigration was corrected to include the area below the weir, using a ratio expansion factor (x1.07 Decker et al. 2003) based on the wetted area of the overall channel.

All species collected at the weir were identified and tallied. At least 100 coho smolts, were measured for fork length (mm) in each marking period. During periods when coho movement was very high, a sub-sample of smolts was measured, but measurements were made on each sample date to minimize bias from sporadic sampling. A systematic procedure, based on a fixed sampling interval, i.e. every 4th or 5th fish, was used to sample randomly. Water temperatures were collected daily at each weir and at the RST locations (Appendix 2).

3.1.4 Mainstem Sampling

Two rotary screw traps, 2 m in diameter, were installed in the Englishman River mainstem to trap juvenile coho migrating downstream and assess the mark-unmarked proportions of the migration. The upper trap (URST) was located 4.0 km from tidal influence at Top Bridge Park, the site used in previous programs. The lower (LRST) was installed in, approximately, the same location as in 2003, along the east side of a wide gravel bar: trap location was adjusted in this general vicinity to improve catches in the first recovery period. The total discharge sampled at the upper site was estimated at 25%, with a similar proportion of the east channel sampled by the LRST. The portion of the smolt migration that moved through the channel on the west side of the gravel bar was unsampled.

All smolts captured in the RSTs were tallied daily by species and mark/unmark type. All smolts with a mark originating from Nature Trust, were measured for fork length (mm) at both sites. Unmarked smolts were also measured; sub-sampling was performed on large catches. Alternating, distinctive, marks (left pectoral and lower caudal) were applied (Pan Jet) to all unmarked smolts recovered by the URST.

4.0 RESULTS AND DISCUSSION

4.1 Nature Trust mark application

During the study, water temperature in the side-channel ranged from 8^0C to 14^0C (Appendix 2) slightly warmer on average (11.0^0C) than the mainstem (7 - 14^0C mean 10.3^0C). Smolt movement from the channel increased with warmer temperatures in late April.

The Nature Trust side-channel produced a total of 3,695 coho smolts between April 21 and June 6. Adjusted for unsampled length, the population estimate is 3,954 smolts. Smolt density was high (2,865 km^{-1}), lying at the upper range of estimates provided by Marshall and Britton (1990) for coastal streams (363 – 3018 km^{-1}). However, the 2005 population was only 67% of the 2004 estimate of 5,892 smolts (Taylor 2004).

Although marking and release of coho from Nature Trust was periodic, the general form of smolt migration from the channel is illustrated in Fig. 2. Peak migration occurred in mid-May, with counts of 389 smolts and 382 smolts on May10 and 15, bridging a period between releases (Appendix 1). Movement had dropped to low levels by the end of May and no further catches were recorded after June 3. Figure 3 illustrates the cumulative proportional catches at Nature Trust and in the 2 RSTs and documents the agreement between mark releases and mainstem movement as well as the end of migration: the step pattern in Nature Trust migration reflects the pattern of mark application.

All but one of the 3,695 smolts captured were marked and released. No mortalities were recorded in any of the 6 retention tests conducted, consequently, no correction to the release totals was required. Although marked smolts were not examined for mark retention, it was anticipated that the short duration between release and subsequent recovery in an RST would minimize dye degradation or tissue loss, and 0% mark loss was assumed. Initial releases of caudal and anal marks from Nature Trust were first recaptured in the URST after 2 and 3 days respectively.

Mark releases varied from 16% (final marking stratum) to 252% (1,181 smolts in mid-program), of the calculated periodic requirement. Daily catches at the start of the study were low, resulting in 50% of the required 468 releases between April 21 and 27. The RSTs could not be fished for 3 days in the 5th marking stratum (May 22 to 28) due to elevated discharge in the mainstem on May 23. Consequently, mark releases were concentrated in the latter portion of the stratum and achieved only 40% of the target (189 smolts). It was anticipated that there might be difficulty in achieving marking targets at the beginning and end of the study, however, the impact on overall population totals was expected to me minor in periods of low smolt abundance.

Totals of 627 upper caudal and 597 anal marked smolts were measured during the program. Mean fork lengths for these groups is given in Table 1, the mean for both mark types was 92.3 mm (SD 11.47).

4.2 Mainstem collections

Three estimates of population size were calculated from the stratified RST data. The first used Nature Trust releases and recaptures at the URST. The second replicated this calculation for LRST data, while the third incorporated the additional marks released from the URST and recaptures in the LRST. These estimates, with associated statistics, are presented in Table 2.

Between April 20 and June 6, the RSTs collected a total of 6,031 smolts, of which 778 were recaptures. Capture probabilities for the upper RST demonstrated significant temporal variation (Pearson chi-square, $\chi 2 = 36.7$, df = 5, $p < 0.001$). Values ranged from 3.4% to 10.7% and averaged 8.2% over all periods, substantially lower than in the previous year (11.2 %: Taylor 2004). Initial adjustments to fishing depth and speed, made during the first recapture period, to balance the efficiency of the RST for both coho and steelhead, combined with a low number of marks, may have affected the number of recoveries, reducing efficiency in this stratum, as anticipated. However, the unexpectedly low efficiency in the second period (5.2%) was likely due to loss of marks through trap failure. Although the URST was the more effective of the 2 traps, capturing 3,431 coho compared with 2,600, it also frequently captured wood debris, which jammed the drum, resulting in the loss of the catch. This was more prevalent at the upper site (April 24, 25, May, 2, 3 and 30), due to public access in the vicinity of the trap. A second, and potentially more serious loss in efficiency resulted the unusual peak in discharge (Fig 4) that curtailed sampling in the release period May 22 to 28 after only 1 day, for a total catch of only 159 smolts for the period (4.2% efficiency). The trend in catches by the URST is illustrated in Fig 2 and suggests that a substantial portion of the 5th stratum population was not sampled. A smaller flood eliminated catches on May 20 but likely had little effect on the capture efficiency of the trap in this period.

The estimate of total smolt numbers using URST data was 45,909 (95% CI 39,320-52,498). The associated error for this estimate is ± 14.4 % in agreement with that used in the planning exercise, but greater than anticipated, given the much larger release of marks from Nature Trust in most periods. Combining all release strata gives a pooled Petersen estimate (PPE) of 41,851 with improved confidence limits (37,547 – 46,155), however, the lack of temporal consistency among capture probabilities, indicated previously, suggests this estimate incorporates substantial bias.

The location of the lower RST constrained sampling to a smaller portion of the river, and trap malfunction due to wood debris was also problematic at this site. Consequently, there was a reduction in total catch compared to the upstream trap (total catches fell to 2,600, Table 2). However, for Nature Trust marks, capture probabilities were not significantly different among temporal strata ($\chi2 = 7.65$, df = 5, $p < 0.177$), with the mean value of 5.1%, (range 3.2% to 7.3%), lower than that of the URST, but an improvement over the 4.2% recorded in 2004. Catches in the LRST also suffered from the high water event in late May, with the lowest catch efficiency (3.2%) recorded for this release period (Table 2). The estimate of migration size from the stratified data was 42,701 (95% CI 37,376 – 48,026) with an associated error of ±12.5%. The lack of variation among strata provides justification for pooling the temporal strata and the PPE was 42,904 (95% CI 37,709 – 48,098) with limited gain in accuracy (±12.1%).

The LRST estimate of smolt abundance from the combined mark groups was similar to the above estimate, 39,567 (95% CI 35,584- 43,550). The expected gain in accuracy from the inclusion of a large number of marks from the URST was somewhat offset by the lower capture probabilities, and the 95% confidence limits, while somewhat improved, were again wider than expected (± 10.1 %). The addition of 3,058 marks from the URST created an increase in mean capture efficiency (7.0%) at the expense of a wider range of values (2.1% to 9.0%), with the lowest estimate corresponding to the second flood event (Fig. 4). Capture probabilities did not improve substantially in the final stratum, as a result of only 1 recapture from the last series of marks from the URST (Table 2). Consequently, capture probabilities were significantly different among strata ($\chi2 = 46.8$, df = 5, $p < 0.001$) and the PPE calculated from these data (36,822, 95% CI 33,946 – 39,698) is also biased low.

In previous years (Decker et al. 2003), adjustment was made to correct for the unsampled mainstem population, below the LRST. This was also performed on the 2004 estimates (Taylor 2004), although with some reservations, since a simple correction factor requires a direct proportionality between smolt production and lineal distance throughout the

Englishman River. The lower river contains proportionately less quality rearing habitat and is likely to be less productive than upstream (Mel Sheng pers. comm.). While the potential error from such an expansion factor would have a small effect on an unbiased estimate it has not been applied in this study.

The adjusted count of smolt output from the Nature Trust channel indicates that 9.3 % of the total smolt migration from the Englishman River was generated by this area. This approximates the 10% estimated to have originated in the channel in 2003 (Schick and Decker 2004) but lies at the lower end of estimates compiled since 1998. However, the current program illustrates the continuing importance of the Nature Trust channel to overall coho smolt production in the Englishman River system.

4.3 Sources of bias in the population estimates

A number of assumptions are required to be fulfilled for the unbiased estimation of population size using a Petersen estimator (e.g. see Seber 1982, Arnason et al. 1996). Of these, marking mortality was assessed during the program and was found to be zero in the short term (24 hrs), population closure was assured by sampling until trap catches were zero, field examination of marking and recovery efforts indicated that marks were applied correctly and visibly and that marks were being correctly identified in RST catches, and equal catchability in the marking sample was assured by marking the entire population of Nature Trust channel. It was assumed that the distance between release and recovery sites (approximately 4 km to the upper trap) would ensure random mixing between marked and unmarked fish, which allows considerable latitude in mark and recovery sampling methods (Schwarz and Taylor 1998). Nevertheless, the practical implementation of the study was more problematic than anticipated, given the large variation displayed by the trap efficiencies, even though the largest impact on capture probability was due to an extreme hydrological event.

Comparison of the strata estimates from the two mark release groups illustrates the similarity between most temporal periods estimated by the LRST data (Figure 5). However, the estimate for stratum 4 (May 17 – 22) represented the peak of migration, based on Nature Trust marks, while the increased capture probability of marks from the URST reduced the equivalent estimate from the combined releases to less than the stratum 3 level (Table 2). Total catches in the two RSTs (Fig 3) while different in magnitude, strongly support peak migration in period 4: unfortunately, additional catches that would have elevated both totals were lost on May 20, due to high water. Similarly, we do not know if substantial numbers of coho passed unsampled, during subsequent flooding in stratum 5.

The most obvious discrepancies among estimates occurred in the first recapture period, where the URST estimate was more than twice those of the LRST (Table 2) and in stratum 2 where the URST (11,837) exceeded the peak estimate for the LRST, calculated with both marks (11,405). Capture probabilities were lower at the URST in both strata (3.4% and 5.2%), while catches were larger (310 and 630) than at the lower site. While it is probable that our assessment of the catchability of early marks was biased low by intermittent sampling, low probability of capture would not solely bias the estimates, unless there was selectivity for unmarked smolts.

The use of stratification is important in avoiding the assumption of constant capture and movement probabilities for all fish that can potentially create significant bias in pooled Petersen estimates. Ideally, catchability should remain stable throughout the study, although most capture gear displays size selectivity (Ricker 1975) which may introduce temporal variation. However, temporal stratification can minimize bias by compensating for events such as fluctuations in discharge or variation in size of migrants over time (Carlson et al. 1998). In addition, the use of two distinct capture methods was expected to minimize bias from capture selectivity, if for example, migration from Nature Trust was found to be size dependent with respect to time (Seber 1982; p86). The 2005 Englishman River data suggest that early mark releases were less catchable than those later in the program, although smolt fork length in these periods was not significantly different (ANOVA Bonferroni adjusted pair-wise comparisons $p>0.05$ in all cases). Comparisons of the size classes of marked versus unmarked smolts indicate the marked population was random with respect to size (URST $\chi 2 = 5.08$, df = 7, p = 0.65, LRST URST $\chi 2 = 4.59$, df = 6, p = 0.60). However, a goodness of fit test on recaptured versus not recaptured smolts showed significant size selectivity by the traps (URST $\chi 2 = 25.1$, df = 6, p < 0.001, LRST URST $\chi 2 = 23.0$, df = 6, p < 0.001). Selectivity was consistent between the traps and, although trap efficiency varied, catches by size class in both RSTs were not significantly different ($\chi 2 = 9.35$, df = 7, p = 0.10). Increased catchability of a segment of the migration does not necessarily produce bias in the stratum estimates, however. Since the marked releases constitute a random sample, the recovery sample i.e. either RST, can be selective as long as this is independent of mark status (Seber 1982). However, the overestimate in stratum 2 for the URST suggests that proportionally fewer marks than unmarked coho were captured. Selection for unmarked smolts may result from stress of capture and marking, or from schooling behaviour, which would create greater variability in the within stratum capture probabilities (Mäntyniemi and Romakkaniemi 2002). Generally, smolt movement is negatively correlated with water temperature and low water temperatures in stratum 1 may have discouraged smolt (marked and unmarked) movement in the mainstem, leading to susceptibility of the estimate to overdispersion. This increases the probability for large groups of smolts to move past the RST uncaught and, consequently, for a substantial portion of stratum releases to be missed when trap efficiency is low. However, any effect of temperature would have been a factor only in the first release stratum. Trap failures and reduced fishing time due to the necessity for modifications to prevent debris entrainment was a probable compounding factor at the URST, particularly with respect to the overestimate in stratum 2. There was quite good agreement between the LRST estimates for strata 1 and 2 and the consistent recapture probabilities for Nature Trust marks indicate that complete mixing of marks had occurred by this point in the river. However, mixing of the marks released from the URST may have been incomplete, since stratum consistency was not maintained for the combined mark groups.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The best estimate of the 2005 smolt outmigration results from the recapture of Nature Trust marks in the lower RST (42,701 ± 5,325 coho). This site exhibited consistent capture probabilities for this mark group and provided stratum estimates that conformed to the migration pattern of overall catches. Unavoidably, the estimate is likely an underestimate of the true migration size due to two period of flooding that prevented recapture sampling in the latter part of May.

The program improved on the design objective of ±15% accuracy (±12.5% with 95% confidence) and accomplished this from catch-recaptures in the less efficient LRST. While almost 1.5 times the design mark requirement was achieved, predicted mark releases were based on the 2004 estimate of efficiency for the URST, and loss in accuracy resulted from the lower efficiency of the LRST. Although the lower site experienced problems with floating debris, trap efficiency for Nature Trust marks increased over the 2004 estimate for all mark types (5.1% versus 4.2%) and improved catches of marks from the URST elevated efficiency to 7%. In contrast, the upper trap had lower efficiency than in the previous year (8.2% versus 11.2%) and intermittent interruptions in sampling, due to debris collection, contributed to reduced catches and, potentially, to inconsistent capture probabilities for marked smolts.

In order to compensate for the possibility of low capture efficiency, particularly at the lower RST, the number of marks released during the program should be maximized. It would be prudent to plan to incorporate marking of Centre Creek smolts into the 2006 program: smolts marked at this site in 2004 totalled 6,548 (Taylor 2004) and would provide a safety margin to maintain accuracy greater than (±15%). The increase in marks, from a different location, early in the program should increase the potential for mixing with the mainstem smolts to reduce overestimation in initial strata.

Since loss of sampling time due to debris has been a constant feature of the program, modification of the RSTs to prevent loss of catch when the drum is prevented from turning should be a priority for the 2006 program.

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Table 1. Summary of coho smolt fork length (mm) by mark type measured at the Nature Trust channel and the upper and lower RST sites.

Site	Mark	n	mean FL	min FL	max FL	SD
Nature Trust	UC[1]	627	92.1	63	132	11.59
	A[2]	597	92.5	67	133	11.35
URST	UC	131	94.7	76	125	8.92
	A	154	93.1	72	123	9.12
	NM[3]	1042	94.3	64	130	9.12
LRST	UC	105	94.7	74	118	8.53
	A	144	95.5	74	119	9.14
	NM	106	95.0	73	127	10.29

[1] UC = upper caudal fin, [2] A = anal fin, [3] NM = no mark

Table 2. Periodic estimates of population size derived from recovery sampling by the upper (URST) and lower (LRST) rotary screw traps. Individual estimates are provided for marks released from the Nature Trust side-channel, and for marked smolts released from the URST. Capture probabilities (trap efficiencies) are provided by release period.

URST

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	lower 95% CL	upper 95% CL	CI %	capture probability
29 April	310	236	8	8189	3283	13095	60%	3.4%
7 May	630	937	49	11837	8803	14870	26%	5.2%
14 May	1026	1181	117	10286	8637	11936	16%	9.9%
21 May	1222	1078	115	11375	9522	13228	16%	10.7%
28 May	123	189	7	2944	1123	4765	62%	3.7%
6 June	120	73	6	1278	459	2097	64%	8.2%
Total	3,431	3,694	302	45,909	39,320	52,498	14.4%	8.2%

LRST Nature Trust marks

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	lower 95% CL	upper 95% CL	CI %	capture probability
29 April	156	236	11	3101	1522	4679	51%	4.7%
7 May	493	937	57	7989	6134	9844	23%	6.1%
14 May	935	1181	86	12717	10281	15152	19%	7.3%
21 May	830	1078	61	14699	11278	18120	23%	5.6%
28 May	82	189	6	2253	787	3719	65%	3.2%
6 June	104	73	3	1943	3418	3567	84%	4.1%
Total	2,600	3,694	223	42,701	37,376	48,026	12.5%	5.1%

LRST Nature Trust & URST marks

Release end date	Catch	Marked Releases	Recaptures	Population Estimate	lower 95% CL	upper 95% CL	CI %	capture probability
29 April	156	442	18	3660	2188	5131	40%	4.1%
7 May	493	1568	85	9012	7338	10685	19%	6.4%
14 May	935	2034	166	11405	9907	12903	13%	8.2%
21 May	830	2144	193	9187	8110	10264	12%	9.0%
28 May	82	377	8	3485	1469	5501	58%	2.9%
6 June	104	187	6	2819	967	4671	66%	3.2%
Total	2,600	6,752	476	39,567	35,584	43,550	10.1%	7.0%

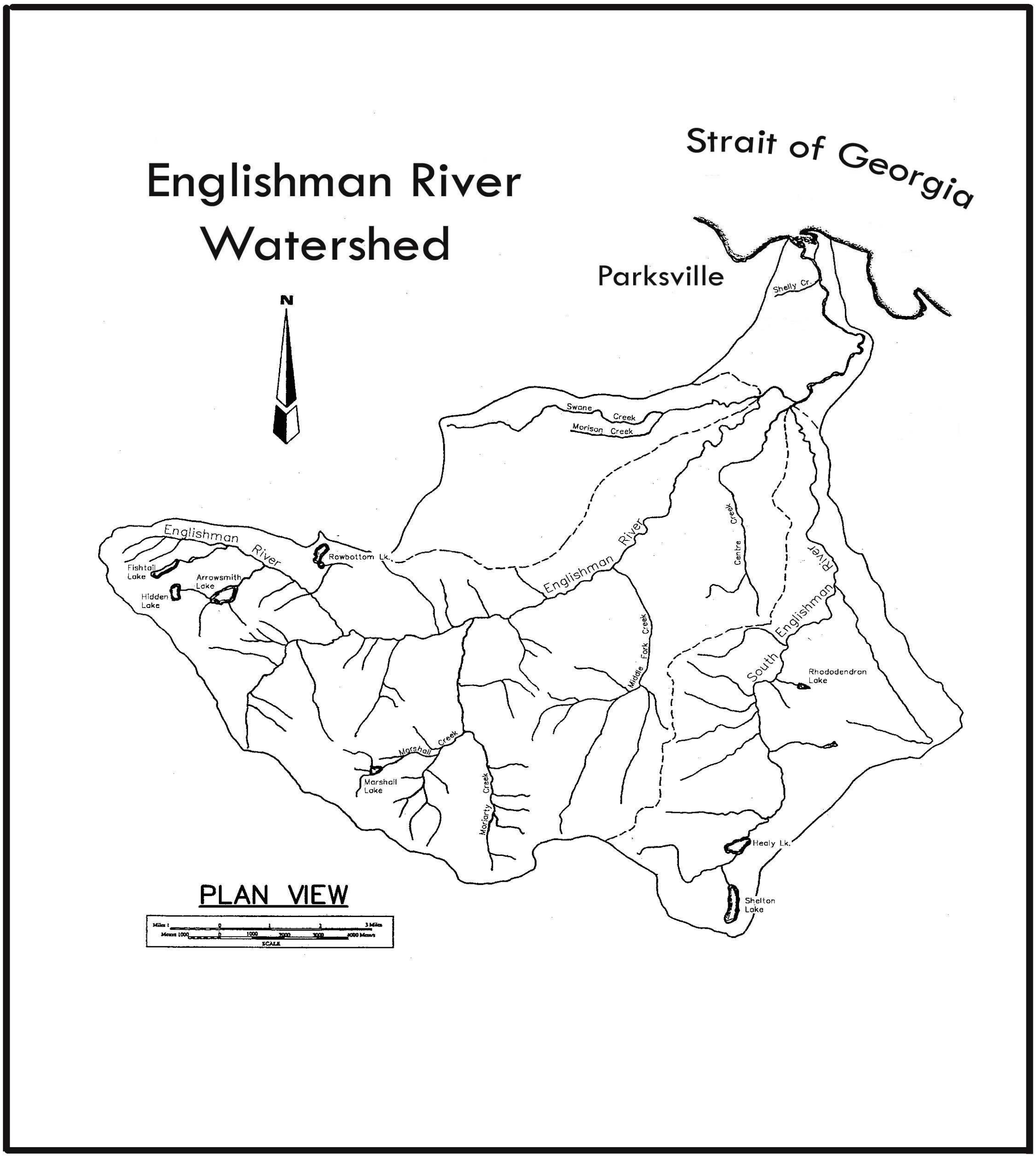

Figure 1. Map of the Englishman River watershed.

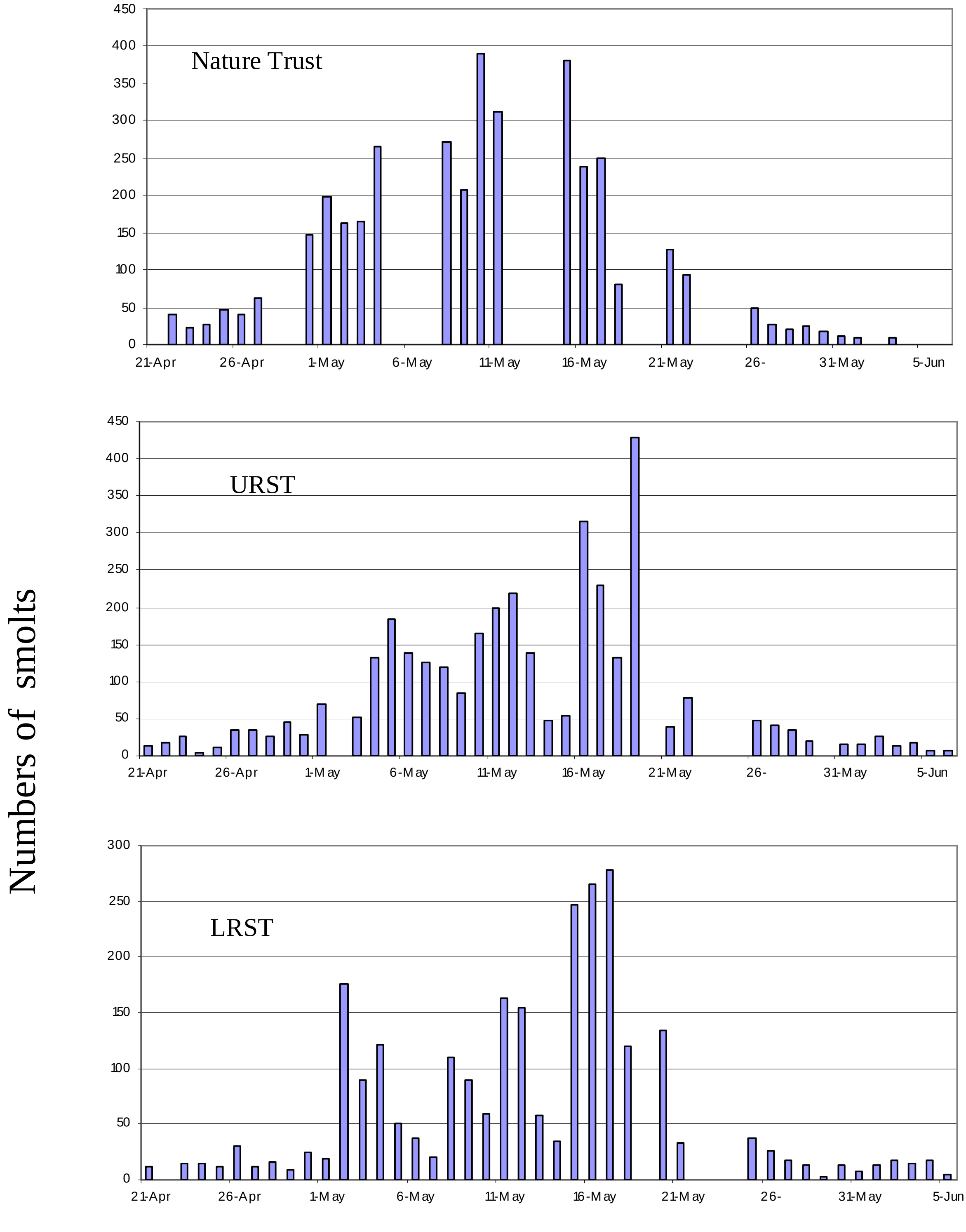

Figure 2. Mark releases from Nature Trust and daily catches in the upper and lower rotary screw traps.

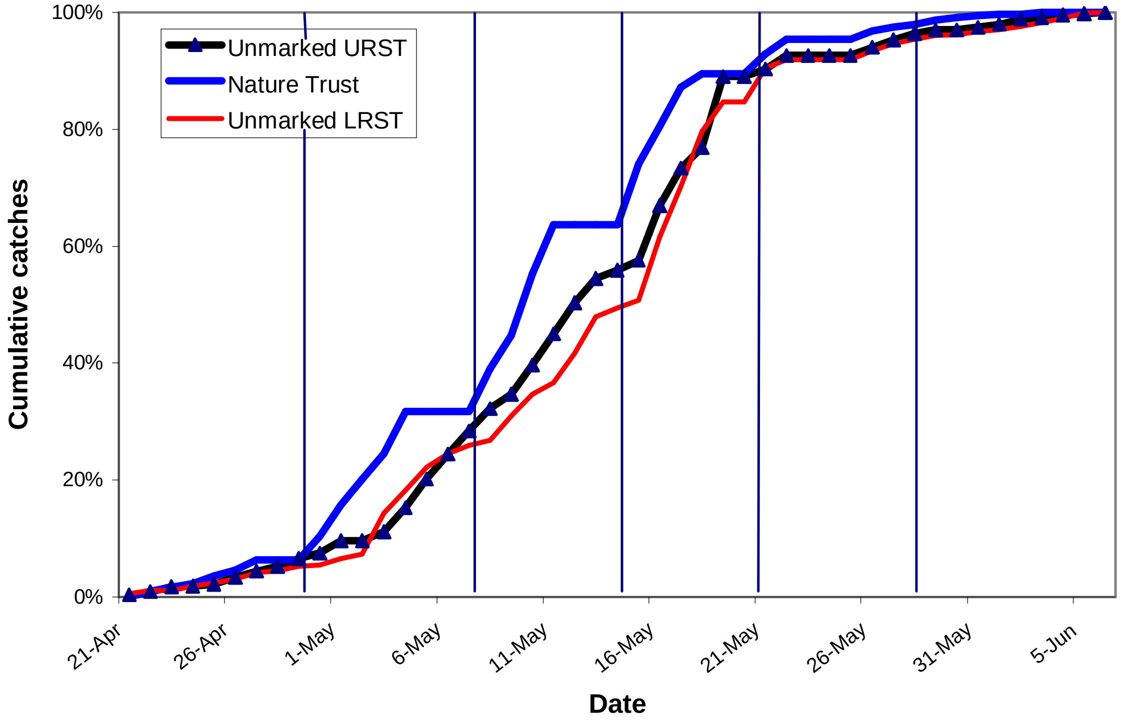

Figure 3. Comparison of cumulative frequency distribution plots of Nature Trust marked releases and unmarked smolts captured in the upper and lower RSTs. Vertical lines delineate the marking strata.

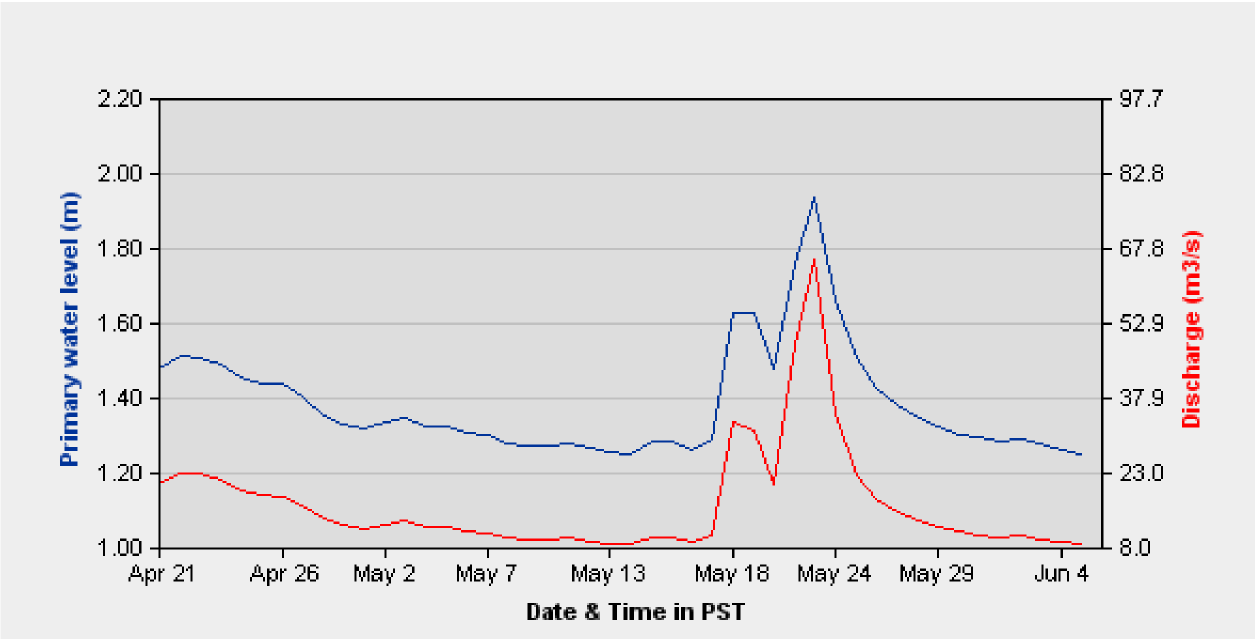

Figure 4. Preliminary water level and discharge for the Englishman River at Water Survey of Canada station #08HB002, during the study. (Data from Environment Canada http://scitech.pyr.ec.gc.ca/waterweb/fullgraph.asp).

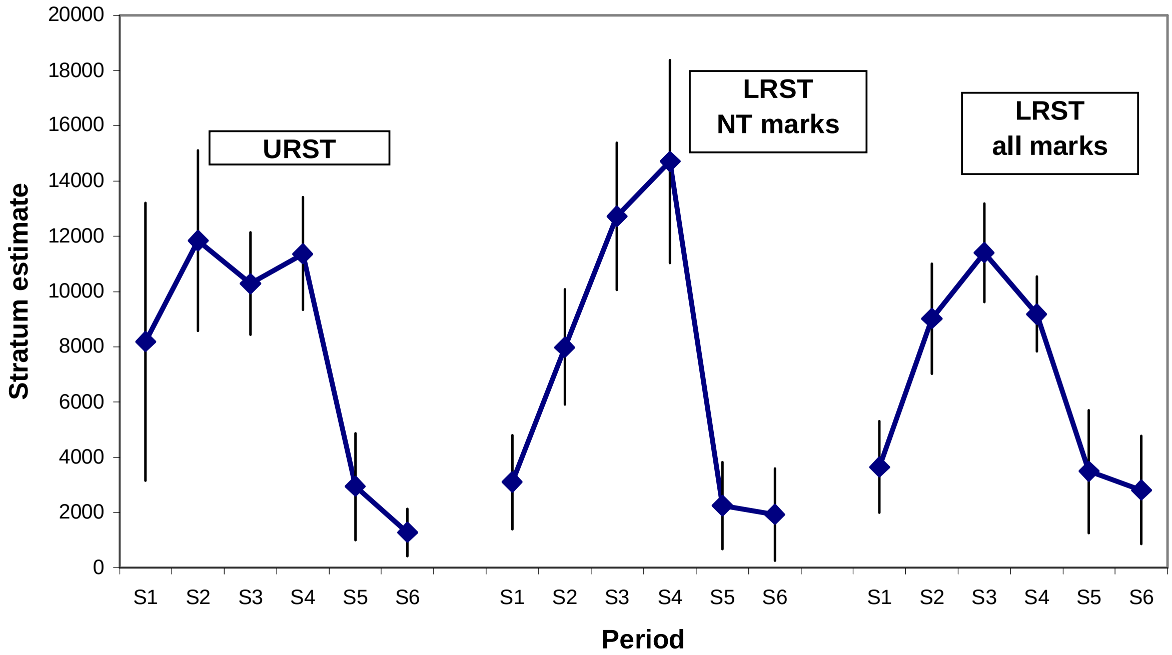

Figure 5. Comparison of stratum estimates of migration, with 95% confidence intervals, from marks released from Nature Trust channel and recaptures in the upper and lower RSTs.

Appendix 1. Captures of coho smolts at Nature Trust channel (NT) and the upper (URST) and lower (LRST) rotary screw traps.

Date	NT	UR	LR
21-Apr	0	14	14
22-Apr	39	17	11
23-Apr	22	26	0
24-Apr	26	5	14
25-Apr	47	10	14
26-Apr	41	34	12
27-Apr	61	35	30
28-Apr	0	26	11
29-Apr	0	45	16
30-Apr	147	29	9
1-May	198	69	25
2-May	162	0	19
3-May	165	52[1]	176
4-May	265	131	90
5-May	0	183	121
6-May	0	139	50
7-May	0	125	37
8-May	272	118	20
9-May	208	85	109
10-May	389	165	90
11-May	312	199	59
12-May	0	218	163
13-May	0	139	155
14-May	0	47	58
15-May	382	55	34
16-May	238	315	247
17-May	249	229	265
18-May	81	133	279
19-May	0	428	119
20-May	0	0	0
21-May	128	40	134
22-May	94	77	33
23-May	0	0	0

Appendix 1. cont'd

Date	NT	UR	LR
24-May	0	0	0
25-May	0	0	0
26-May	48	47	38
27-May	26	42	26
28-May	21	34	18
29-May	24	20	13
30-May	18	0	3
31-May	12	16	13
1-Jun	9	16	7
2-Jun	0	26	13
3-Jun	10	12	18
4-Jun	0	17	15
5-Jun	0	6	18
6-Jun	0	7	4
Totals	3694	3431	2600

[1] Mortalities resulting from trap failure due to debris.

Appendix 2. Daily water temperatures (0C) at the the RST sites and Nature Trust channel

Date	Mainstem LRST	Mainstem URST	Nature Trust channel
21-Apr	7	7	8
22-Apr	7	7	9
23-Apr	9	9	9
24-Apr	8	8	9
25-Apr	8	8	10
26-Apr	9	9	11
27-Apr	10	10	10.5
28-Apr	9	9	10.5
29-Apr	9	9	10
30-Apr	9	9	11
01-May	9	9	11
02-May	11	11	10.5
03-May	10	10	11
04-May	10	10	11
05-May	10	10	11
06-May	10	10	11
07-May	10	10	11
08-May	10	10	11
09-May	10	10	10
10-May	10	11	13
11-May	10	12	13
12-May	11	11	13
13-May	10	11	13
14-May	11	11	12.5
15-May	12	12	12.5
16-May	11	11	12
17-May	11	10	12
18-May	11	11	12
19-May	9	9	11
20-May	9	9	11
21-May	9	9	11

Appendix 2. cont'd

Date	Mainstem LRST	Mainstem URST	Nature Trust channel
22-May	9	9	10
23-May	9	9	9
24-May	9	9	9
25-May	9	9	9
26-May	10	10	12
27-May	12	12	14
28-May	12.5	12.5	14
29-May	13	13	14
30-May	13	13	13
31-May	13	13	14
01-Jun	14	12	12
02-Jun	13	13	13
03-Jun	13	13	12
04-Jun	13	13	12
05-Jun	12	12	-
06-Jun	11	11	-

Appendix 3. Mark releases and recovery of Nature Trust marks (A and B) and Nature Trust with URST marks (C) by recovery stratum, in the two RSTs.

(A) URST NT marks

		Recovery stratum					
Release stratum		1	2	3	4	5	6
end date	coho marked	1-May	7-May	15-May	22-May	28-May	6-Jun
28-Apr	236	8					
7-May	937		49				
14-May	1181			117			
21-May	1078				115		
28-May	189					7	
6-Jun	73						6
	unmarked catch	302	581	909	1107	116	114

(B) LRST NT marks

		Recovery stratum					
Release stratum		1	2	3	4	5	6
end date	coho marked	1-May	7-May	16-May	22-May	28-May	6-Jun
28-Apr	236	11					
7-May	937		57				
14-May	1181			86			
21-May	1078				60		
28-May	189					6	
6-Jun	73						3
	unmarked catch	145	436	849	770	76	101

(C) LRST both marks

		Recovery stratum					
Release stratum		1	2	3	4	5	6
end date	coho marked	1-May	7-May	16-May	22-May	28-May	6-Jun
28-Apr	442	18					
7-May	1568		85				
14-May	2034			166			
21-May	2144				193		
28-May	377					8	
6-Jun	187						6
	unmarked catch	138	408	769	637	74	98