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

By

J.A. Taylor

Submitted to

Fisheries and Oceans Canada
Habitat and Enhancement Branch

November 2004

ABSTRACT

The contribution from two constructed side-channels and a natural off-channel area, to overall coho smolt production in the Englishman River, was assessed through a mark-recapture program between 30 March and 28 May, 2004. Overall emigration from the system, during the study, was estimated to be 41,331 ± 3,677 smolts, of which 16% originated in the constructed channels: 2% Weyerhaeuser and 14% Nature Trust. Centre Creek, a natural tributary, contributed a further 16% to measured production. Smolt density in Nature Trust channel (4,270 km^{-1}) was much greater than in Weyerhaeuser channel (799 $smolts.km^{-1}$), or in Centre Creek (1,259 $smolts.km^{-1}$). Termination of sampling prior to the end of smolt migration resulted in underestimation of the size of the outmigration. However, the estimates are expected to adequately characterize the proportional contributions from the mark release sites.

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. A number of population estimates of juvenile coho and other species using the channels were produced in the 1990's. However, these employed different methodologies and were difficult to compare directly (Miller 1997). In order to quantify the contribution of juvenile coho from the constructed channels to the Englishman system, a series of projects were initiated in 1998 using mark-recapture. The present report describes the sixth project in this series.

2.0 METHODS

The 2004 program was based on the design of previous studies initiated in 1998 (Decker at al. 2003). In its simplest form, the design provides for 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. Marks are released in conjunction with enumeration of a substantial portion of the smolt outmigration from the two side-channels (Nature Trust and Weyerhaeuser) and, since 2001, 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). Generally, a series of estimates of population size are obtained from geographical stratification (release and recovery locations), and, in a majority of years, the population estimates have been obtained by pooling the temporal strata (release periods).

Although the design of the 2004 program could not be implemented analytically, an important aspect was the incorporation of stratification, to ameliorate the potential effect of temporal changes in rotary screw trap efficiency. The basic method employed in 2004 mirrored previous programs, with the release of marked smolts from the side-channels and Centre Creek back into the population to be subsequently recovered downstream and counted to estimate total abundance for a segment of the population. The design incorporated the application of unique mark types by marking period, to permit the use of a stratified estimator and to provide an estimate of capture probability (trap efficiency) over time. Unfortunately, the procedure requires temporal stratification such that each trap efficiency trial is discretely paired with one capture period. In 2004, some mark types were duplicated and, at Centre Creek, the same mark was applied in sequential time periods. Consequently, recaptures could not be reliably tracked to a release period and I was forced to collapse the temporal strata and estimate total population size using a modified Petersen estimator.

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. 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.

2.2 Population Estimates

2.2.1 Channel and tributary smolts

Counts of the number of smolts that migrated from the constructed channels and from Centre Creek were made at converging downstream weirs: description of the construction and operation of these weirs can be found in Decker et al. (2003). Weir integrity was maintained throughout the project at all sites and, consequently, the total counts underestimate population size for the upstream portions of habitat only as a result of early removal (May 28) due to budgetary constraints. The Centre Creek weir was located just upstream from the confluence with the Englishman mainstem and provided a total count for that tributary. The other two weirs were located, respectively, 250 m and 100 m above the outlets of the Weyerhaeuser and Nature Trust channels. Estimates of the total populations in these channels, including areas below the weirs, were derived from the smolt counts using ratio expansion factors based on the wetted area of the overall channel versus that above the weir. These factors were 1.3 for the Weyerhaeuser Channel and 1.07 for Nature Trust.

The weirs were operated daily from 30 March to 26 May (Nature Trust was sampled until 28 May). All species collected at the weir were identified and tallied. A majority of juvenile coho and a portion of steelhead smolts were measured for fork length (mm). During periods when coho movement was very high, a sub-sample of smolts was measured, but measurements were made on a daily basis so that bias from sporadic sampling should not affect estimates of mean fork length. Water temperatures were collected daily at each weir and at the RST locations (Appendix 1).

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 at two locations in the lower river. In 2004 all juvenile coho > 65 mm were considered to be smolts. This differed from earlier programs where smolts and yearling parr were differentiated by larger size criteria: > 79 mm in 1998 and 1999 and > 70 mm in 2001 (Decker et al. 2003). In 2002, all sizes of yearling coho were marked (Schick and Decker unpublished data). Marks were stratified by time period and Centre Creek smolts were marked differently than fish from the constructed channels. The primary mark type was a sub-dermal tattoo of Alcian Blue dye, applied to a fin using a Pan Jet dental inoculator (Herbinger et al. 1990). The range of mark types was expanded by the use of caudal fin clips, in order to maximize the number of marks that could be released daily. This eliminated the need to employ less reliable tattoo locations that produced, for example, fin splitting, or those areas with less visible results.

2.2.2 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 the site used in previous programs. The lower (LRST) could not be installed in the same location as previously, due to changes in the thalweg. It was moved approximately 200 m upstream from the original site to the east side of a 5 m wide gravel bar. At this site, the total discharge sampled was less than the 25% estimated for both traps in previous years and the unknown portion of smolt movement 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. Sub sampling was conducted daily, at both sites, for the measurement of fork length (mm). A series of unique marks (Pan Jet) was applied to all unmarked smolts recovered by the URST over the 4 temporal strata.

2.2.3 Modified Petersen Mark-Recapture.

The modified Petersen estimate (Chapman 1951) 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:

$$N^* = \frac{(M+1)(C+1)}{R+1} - 1 \qquad (1)$$

where

N^* = estimate of population size

M = number of marked smolts

C = number of smolts in the RST catch

R = number of recaptured marks.

We did not reduce the estimate by 1, since this is a negligible correction at the population levels encountered by the study.

The tally of marked smolts from RST catches represents sampling without replacement and, hence, the distribution of R for ranges of M and C, 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 N* is adequate, in the form:

$$V(N^*) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)} \qquad (2)$$

(see Seber 1982 for conditions to satisfy an approximately unbiased estimate of variance) and approximate 95% confidence limits for N* are:

$$\pm 1.96\sqrt{V(N1^*)} \qquad (3)$$

In previous years the total estimate with confidence bounds was expanded to compensate for the location of the furthest downstream RST (Decker 2003). This was performed on the 2004 estimates, although with some reservations, since avoidance of bias requires a direct proportionality between smolt production and lineal distance throughout the Englishman River. The lower river is likely to be less productive than upstream, but there have been no studies to substantiate this. In any case, the potential bias is likely to be small in comparison with the underestimate of population size resulting from truncation of the sampling program, as described later. The multiplication factor, to adjust the population derived from the lower RST data, was 1.07: the lower RST was positioned further upstream in 2004, hence the larger expansion factor in comparison with previous programs.

3.0 RESULTS AND DISCUSSION

3.1 Coho movement from the side-channels and Centre Creek

Daily counts of coho smolts migrating from the Weyerhaeuser and Nature Trust side-channels and from Centre Creek were initiated on 30 April and concluded on, respectively, 26 May, 28 May and 26 May. During the study, water temperature in the side-channels ranged from 5^0C to 14^0C, while Centre Creek was slightly warmer at 7^0C to 13.5^0C (Appendix 1). In contrast, the mainstem was initially cooler (4.5^0C) and reached a slightly lower maximum temperature (13^0C).

The total count of juvenile coho from the Weyerhaeuser channel was only 584 individuals, the lowest of any of the study years; although the unadjusted estimate of 778 smolts in 1998 was similar (Decker et al. 2003). In contrast, Nature Trust produced 5,507 smolts approaching the total from the much longer Centre Creek (6,549). Adjusted for unsampled length, the estimates from the constructed channels are, respectively, 759 and 5,892 smolts. Smolt densities were very high in the Nature Trust Channel (4,270 km^{-1}), exceeding the range of estimates provided by Marshall and Britton (1990) for coastal streams. Smolt density in the Weyerhaeuser Channel did not achieve the natural level of Centre Creek (799 smolts.km^{-1} versus 1259 smolts.km^{-1}) but was within the lower part of the range compiled by Marshall and Britton (1990: 363 – 3018 km^{-1}).

Migration patterns from the side-channels and Centre Creek were noticeably different. Daily movements of coho smolts from the various areas are illustrated in Figure 2. Both the Weyerhaeuser and Nature Trust channels displayed a bimodal movement, with earliest outmigration from the former. Peak migration in both channels occurred on 19 May, with, respectively, counts of 110 smolts and 933 smolts. The latter was delayed by the weir configuration and occurred in conjunction with a modification to the pipe leading to the holding box, to prevent smolts from exiting back into the channel. Smolt movement from Centre Creek was also constrained by the weir construction. In this case, the initial positioning of the trap box resulted in limited flow through the intake pipe. Consequently, smolts were not attracted into the trap box. Adjustment of the box and pipe was rewarded by the large peak movement of 1,850 smolts on 4 May.

Catches of smolts at all three weirs remained above 10 $smolts.day^{-1}$ at the conclusion of the sampling program (Fig. 2), suggesting that the outmigration was not complete. In particular, movement from the Weyerhaeuser and Nature Trust channels was still very high on the last sampling dates; 45 $smolts.day^{-1}$ and 78 $smolts.day^{-1}$. In the case of the former, this exceeded the mean rate of daily movement of 23 $smolts.day^{-1}$.

Mean fork length of smolts (Fig. 3 and Appendix 2) was significantly different at all sites (ANOVA Bonferroni-adjusted pair wise comparison $p<0.001$ all cases), although this may also reflect the large number of measurements made at most locations: very large samples tend to produce significant differences because of the power of the test.

3.2 Mainstem collections

Over the course of the program, a total of 12,631 marked smolts were released from the Weyerhaeuser and Nature Trust side-channels and from Centre Creek. The totals of marked releases from the constructed side-channels were, respectively, 584 and 5,499 individuals with the remaining 6,548 smolts from Centre Creek. Catches in the 2 mainstem RSTs totalled 5,762 individuals, of which 2,060 smolts were recaptures. The various estimates of population size and associated statistics derived from the combinations of catches and recaptures are presented in Table 1. In all cases the number of marks released and catches in the RSTs were summed over the 4 capture periods.

Capture probabilities for the upper RST averaged 11.2 % (Table 1), similar to the mean value of 12.5 % recorded in 2002 (Schick and Decker 2003). Estimates were not significantly different for the side-channels (10.8 %) and Centre Creek smolts (11.5 %: Pearson chi-square, $\chi 2 = 1.16$, $df = 1$, $p = 0.28$). As a result, the estimate of population size using the combined releases and catches from the side-channels and Centre Creek is unbiased with regards to variation in trap efficiency for these segments of the population. The estimate of total smolt numbers using the combined catches by the upper RST was 37,002 (95% CI 34,897 – 39,107). Precision for this estimate (± 6 %) was greater than that calculated using the individual mark groups (Table 1) as a function of the larger number of marked fish.

The new location of the lower RST permitted a smaller portion of the river to be sampled, and debris caused the trap not to function on 10 occasions. Consequently, there was a reduction in total catch compared to the upstream trap (1,624 versus 4,138; Table 1). Mean capture probability for the various mark groups also declined, although this is not a direct function of catch size. Estimates ranged from 3.9 to 4.5 % with a mean of 4.2 % (Table 1). However, there was no significant difference in trap efficiency among the three mark groups ($\chi2 = 1.91$, df = 2, p = 0.39), so combining the mark and capture totals would be expected to contribute little or no bias to the estimate of population size. The estimate of smolt abundance from the combined mark groups was 38,627 (95% CI 35191 - 42063), while the individual estimates ranged from 36,214 (side-channels) to 40,932 (upper RST). The gain in precision from the use of all groups was more pronounced than shown above for the equivalent URST estimates. The widest confidence limits were associated with the use of the smaller number of upper RST releases alone (± 19 %), while combining all mark groups increased precision to (± 9 %). The increase in total marks due to the contribution from the URST (110; Table 1) was offset by the reduction in catch in the lower RST (1,624 smolts versus 4,138 smolts), therefore, overall precision was not quite as good as in the previous estimate. However, the LRST catches included coho from the lower river that were not sampled by the upstream trap and we recommend the use of the combined marks estimate of 38,627 smolts as, potentially, the most accurate estimate of the overall migration. Adjustment to correct for the unsampled mainstem population, below the LRST, expands the estimate to 41,331 (± 3,677 smolts; Table 2). Although the release of marks from the URST provided greater conformity to mainstem migration timing as described by LRST catches (Fig. 4), the potential to gain accuracy for the early, relatively minor segment of the population that migrated in April, is overshadowed by the loss of precision associated with the smaller number of marks (given the release of 2,795 marks from the URST, approximately 4,700 smolts would have had to be examined to attain an error of ± 10% in 95% of trials: based on formulae by Robson and Regier 1964).

The adjusted counts of smolt output from the constructed channels and from Centre Creek indicate that 16 % of the total smolt migration from the Englishman River was generated by each of these areas (Table 2). These data equal the16% estimated to have originated in the side-channels in 2002 (Schick and Decker 2003), although there was a lower contribution from the Weyerhaeuser Channel (1.8%) and greater production in Nature Trust (14.3%) in 2004. The current program confirms the importance of, particularly, the Nature Trust channel to overall coho smolt production in the Englishman River system.

3.3 Sources of bias in the population estimate

The design of the 2004 program required application of 12 distinct marks to distinguish two application sites (side-channels plus Centre Creek and the upper RST) and 6 time strata: ultimately 4 strata were examined as a result of financial constraints. Unfortunately, re-allocation of specific marks based on ease of application and subsequent recognition, in conjunction with the use of a unique mark for Centre Creek smolts, created errors in mark application. As a result, recoveries could not be accurately assigned to their respective release strata, and the data had to be pooled to generate the Peterson estimate. This may have increased the susceptibility of the estimates of abundance to bias. A number of assumptions are required to be fulfilled for the unbiased estimation of population size using a Petersen estimator. These have been dealt with in detail by a number of authors e.g. Seber (1982), Arnason et al. (1996) and need only be stated briefly here, in conjunction with examination 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 not assessed during the program, but was assumed to be very low in accordance with previous studies (Schick and Decker 2003).

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. Since the project was concluded prior to cessation of migration, we must be satisfied with an acknowledged underestimate of population size.

III. All smolts share the same probability of capture, or, an equal probability of being examined for marks – there was no selective sampling strategy for mark releases from the various sites and all but a small number of smolts were marked. 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 could not be addressed in this program.

IV. Constant probability of capture – ideally, catchability should remain stable throughout the study although most capture gear displays size selectivity (Ricker 1975). Temporal stratification can minimize bias by compensating for events, such as fluctuations in discharge or variation in size of migrants over time. While the present study was designed to incorporate temporal strata, as noted above, in its absence we cannot assess the degree to which such factors may have biased the overall estimate. Examination of the size distribution of recaptured smolts suggested that these were larger than either the unmarked mainstem smolts or the total population of marks. However, this may have been an artefact of sampling, since RSTs tend to select for smaller fish that have lesser avoidance abilities.

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 would not have been an issue in this study except for the early termination of sampling. Since the time of travel of fish from the various release sites to the recapture sites is not known, some unknown portion of the final mark releases may not have had the opportunity of being sampled in RST catches. This would result in a degree of upward bias in the estimates, although the overall effect may have been minor. For example, eliminating the final 78 marks released from Nature Trust channel would reduce the total system estimate by approximately 200 coho, or 0.5% of the migration.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The estimate of smolt abundance (41,331 ± 3,677 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 (loss of stratification, premature conclusion of sampling) while others were either not specifically addressed (mortality and marking effects) or potentially occurred as a function of the sampling methodology (size selective capture). However, although the program produced an underestimate of smolt abundance, it is probable that most of the outmigration was sampled, both in the mainstem and at the channel/tributary weirs. There was fairly good agreement among the rates of migration illustrated for the channels and mainstem in the latter part of the study (Fig. 4), although Centre Creek may have reached the end of migration while the other areas did not (Fig. 3). Consequently, the proportional contributions estimated for the side-channels and Centre Creek are likely representative of the overall geographical distribution of these populations. Clearly, there is agreement between the current estimate of side-channel contribution and that estimated in previous years of the study (e.g. Schick and Decker 2003), that suggests that the side-channels provide a much larger contribution to the smolt output (16%) than would be expected on the basis of channel length (8% of the system length). However, a number of changes to the program are required to provide a more robust estimate of the total numbers of coho that form the outmigration from the Englishman River system.

The use of mark-recapture methods to assess population size are commonly, and perhaps, most widely, implemented through a Petersen estimator (Seber 1982), which has the advantage of simplicity of application and of primary assumptions. However, procedural ease can be offset, in all but the simplest cases, by failure to address a number of factors that may substantially bias results. Consequently, a variety of methods have been developed to accommodate more complex situations. These tend to be based on maximum likelihood methods (Arnason et al. 1996), Bayesian methods (Gazey and Staley 1986 and Mäntyniemi and Romakkaniemi 2002) or the more esoteric "resighting" models based on passive integrated transponder (PIT) tags (Skalski 1998 and Brakensiek 2002). However, not every situation calls for the substantial increase in effort and cost associated with refined methodologies, and, as well, some studies, including early versions of the present program (Decker et al. 2003) have indicated that the Petersen estimator can be robust to violations of the assumptions of constant catchability (see also Schwarz and Dempson 1994) and can perform as well as stratified estimators, and with greater precision, in some circumstances (Schubert 2000). Perhaps the best test for the utility of the methodology remains the use for which the estimates are intended. Robson and Regier (1964) suggest that estimates having greater than 25% error with a probability of < 5% are suitable for accurate management work, while an error > 10% with the same probability is appropriate for research. The estimate in the present study achieved ± 9%, largely as a result of the large number of marks released. It is likely that the Petersen estimator will provide satisfactory levels of precision and accuracy, to achieve the goals of this program, particularly if we can minimize bias in a cost effective manner. 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. However, by utilizing temporal stratification to create fairly short periods of consistent trap efficiency, e.g. after Carlson et al. (1998), we can minimize bias and lower the complexity of multiple mark releases with a concomitant reduction in field crew costs.

The principal recommendations for future programs are:

I. Scheduling the sampling period to encompass a majority of smolt movement. If budgetary constraints preclude sampling throughout the period of migration, sampling should be initiated later than in 2004 to ensure that the conclusion of emigration is represented in catches. Less than 5% of upper RST catches and < 3% of lower RST catches were obtained up to 25 April, while an unknown, but probably much larger portion of the migration occurred after sampling ceased on 28 May.

II. Stratification is essential to reduce potential bias resulting from periods of unequal capture efficiency. I recommend that the complexities of multiple mark releases are eliminated by adopting a series of releases from one or two weir sites, each discretely paired with a recapture period. One mark will suffice in this system and release and recapture tallies will be simplified.

III. A system for sampling catches (marking and recapture) for fork length is required to assess size selectivity by the RSTs. Systematic proportional sampling, based on catch size should be sufficient.

IV. Finally, improvement or selection of a new RST site in the lower river should be investigated. The upper site had better capture efficiency (11%) than the lower site (4%) in 2004 but does not assess the smolt population within the 4km of river above tidal influence. The furthest downstream site that will produce at least 10% catch probability should be the goal for recovery sampling.

5.0 ACKNOWLEDGEMENTS

Thanks to Mel Sheng for administering the program and for his input into the study design. Clayton Young, Community Fisheries Development Centre Central Vancouver Island, co-ordinated the field program. Jeff Young, Ardith Turney, Bob Brown and Mike Edwards counted, marked and measured coho smolts at the channel and RST sites. Thanks also to Mr. Kerry O'Conner for permission to access the lower RST site through his property.

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.

Brakensiek, K.E. 2002. Abundance and Survival Rates of Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Prairie Creek, Redwood National Park. Unpubl. MSc Thesis submitted to Humboldt State University, California.

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. Canada. 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.

Cochran, G. 1977. Sampling techniques. 3rd ed. John Wiley and Sons, New York.

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. Rpt. Fish. Aquat. Sci. 2442 : 53p

Gazey, W. J. and M. J. Staley. 1986. Population estimation from mark-recapture experiments using sequential Bayes algorithm. Ecology. 67(4): 941-951.

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. Ms. Rep. Fish. Aquat. Sci. 2058: 46p

Mäntyniemi, S. and A. Romakkaniemi. 2002. Bayesian mark-recapture estimation with application to a salmonid smolt population. Can. J. Fish. Aquat. Sci. 59: 1748-1758.

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.

Plante, N. 1990. Estimation de la taille d'une population animale à l'aide d'un modèle de capture-recapture avec stratification. M.Sc. thesis, Université Laval, Quebec.

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.

Schwarz, C.J. and J.B. Dempson. 1994. Mark-recapture estimation of a salmon smolt population. Biometrics 50: 98-108.

Skalski, J.R. 1998. Estimating season-wide survival rates of outmigrating salmon smolt in the Snake River, Washington. Can. J. Fish. Aquat. Sci. 55: 761-769.

Table 1. 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 Weyerhaeuser and Nature Trust side-channels combined, and from Centre Creek and for marked smolts released from the URST. Capture probabilities (trap efficiencies) are provided by mark group.

URST

	Catch	Marked Releases	Recaptures	Population Estimate	lower 95% CL	upper 95% CL	CI %	capture probability
All locations	4138	12631	1412	37002	34897	39107	6%	11.2%
Sidechannels	4138	6083	659	38154	35197	41111	8%	10.8%
Centre Creek	4138	6548	750	36094	33456	38731	7%	11.5%

LRST

	Catch	Marked Releases	Recaptures	Population Estimate	lower 95% CL	upper 95% CL	CI %	capture probability
All locations	1624	15426	648	38627	35191	42063	9%	4.2%
URST	1624	2795	110	40932	33259	48606	19%	3.9%
Sidechannels	1624	6083	272	36214	31688	40741	12%	4.5%
Centre Creek	1624	6548	266	39858	34818	44898	13%	4.1%

Table 2. Summary of populations (N) counted from the Weyerhaeuser and Nature Trust side-channels and from Centre Creek, and estimated for the Englishman system, with expansion, where appropriate, to account for unsampled areas.

Site	N	± 95% CI	CI %	length (km)	smolt density /km	% contribution to system
Weyerhaeuser	759	-	-	0.95	799	1.8
Nature Trust	5892	-	-	1.38	4270	14.3
Side-channels total	6651	-	-	2.33	2855	16.1
Centre Creek	6549	-	-	5.2	1259	15.8
Mainstem + Centre Creek	34680	3677	11	31.0	1119	83.9
Total system	41331	3677	9	33.4	1237	100.0

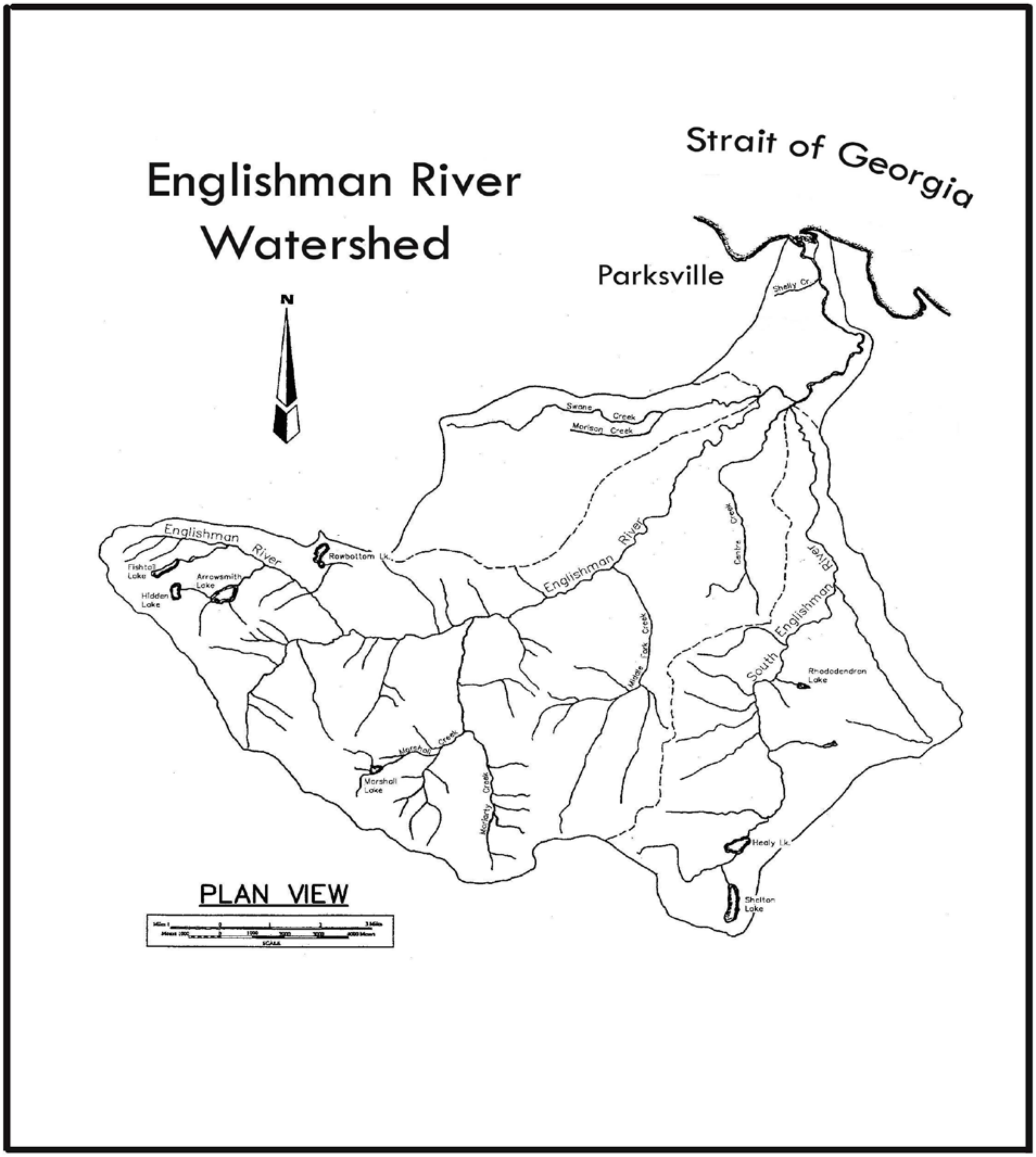

Figure 1. Map of the Englishman River watershed.

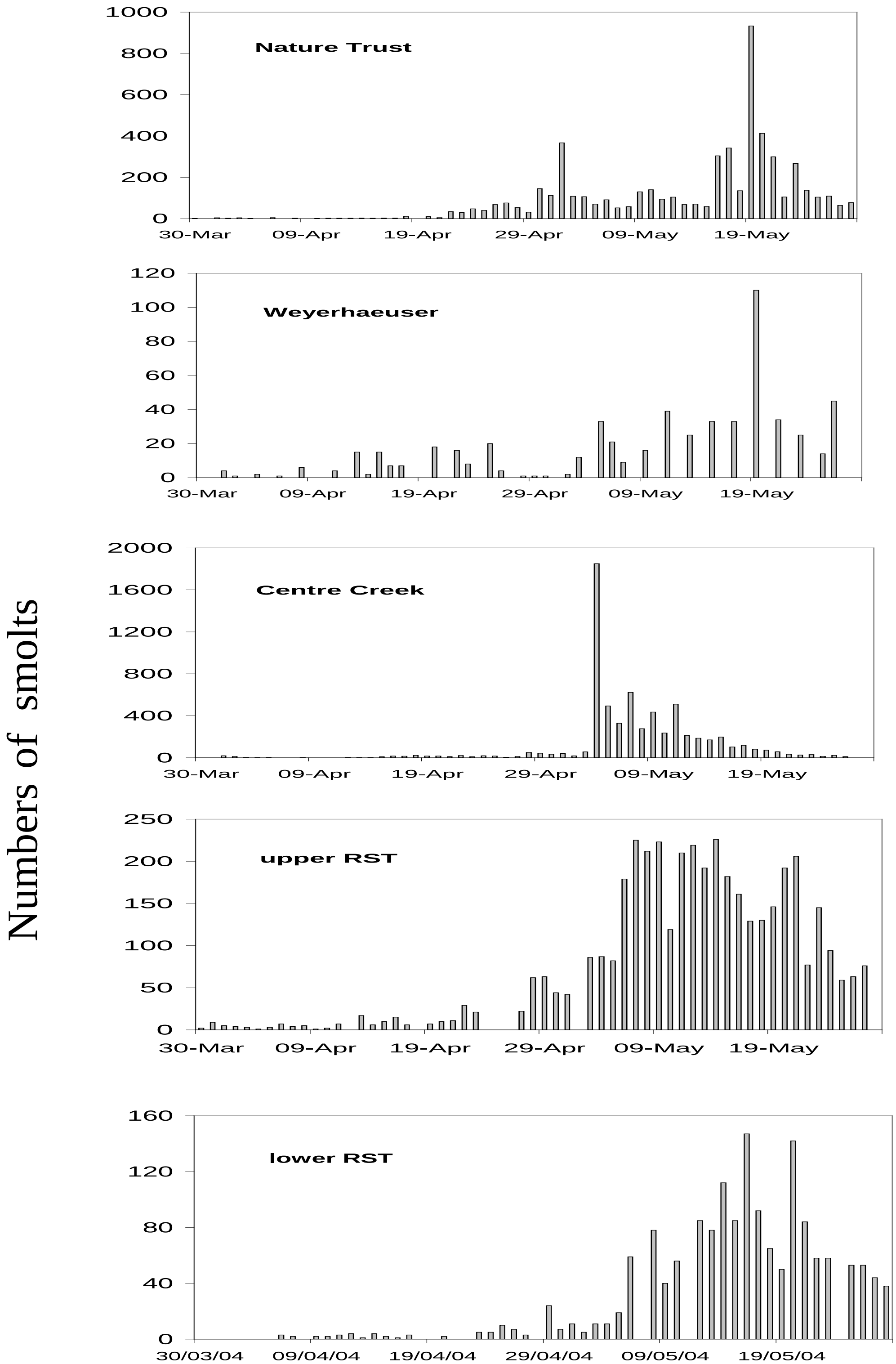

Figure 2. Daily counts of coho from the constructed channels and Centre Creek and daily catches in the upper and lower rotary screw traps.

-

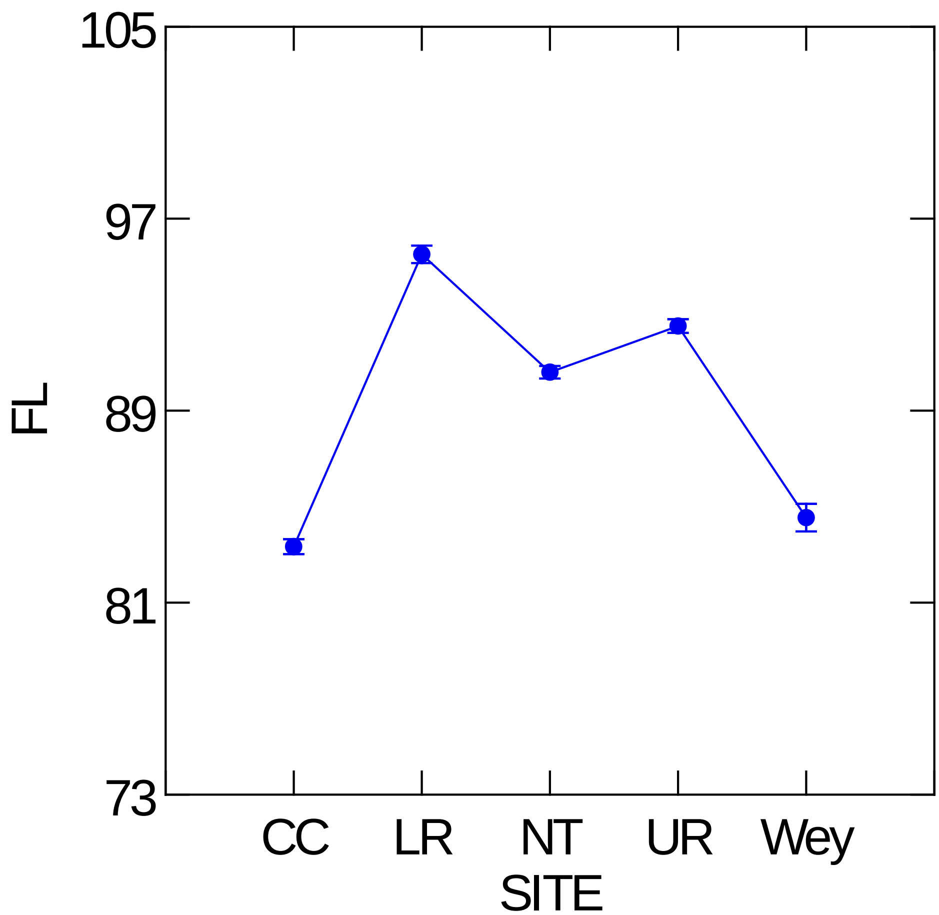

Fig. 3. Comparison of fork length (mm) among the Nature Trust and Weyerhaeuser channels, Centre Creek and the lower and upper RSTs.

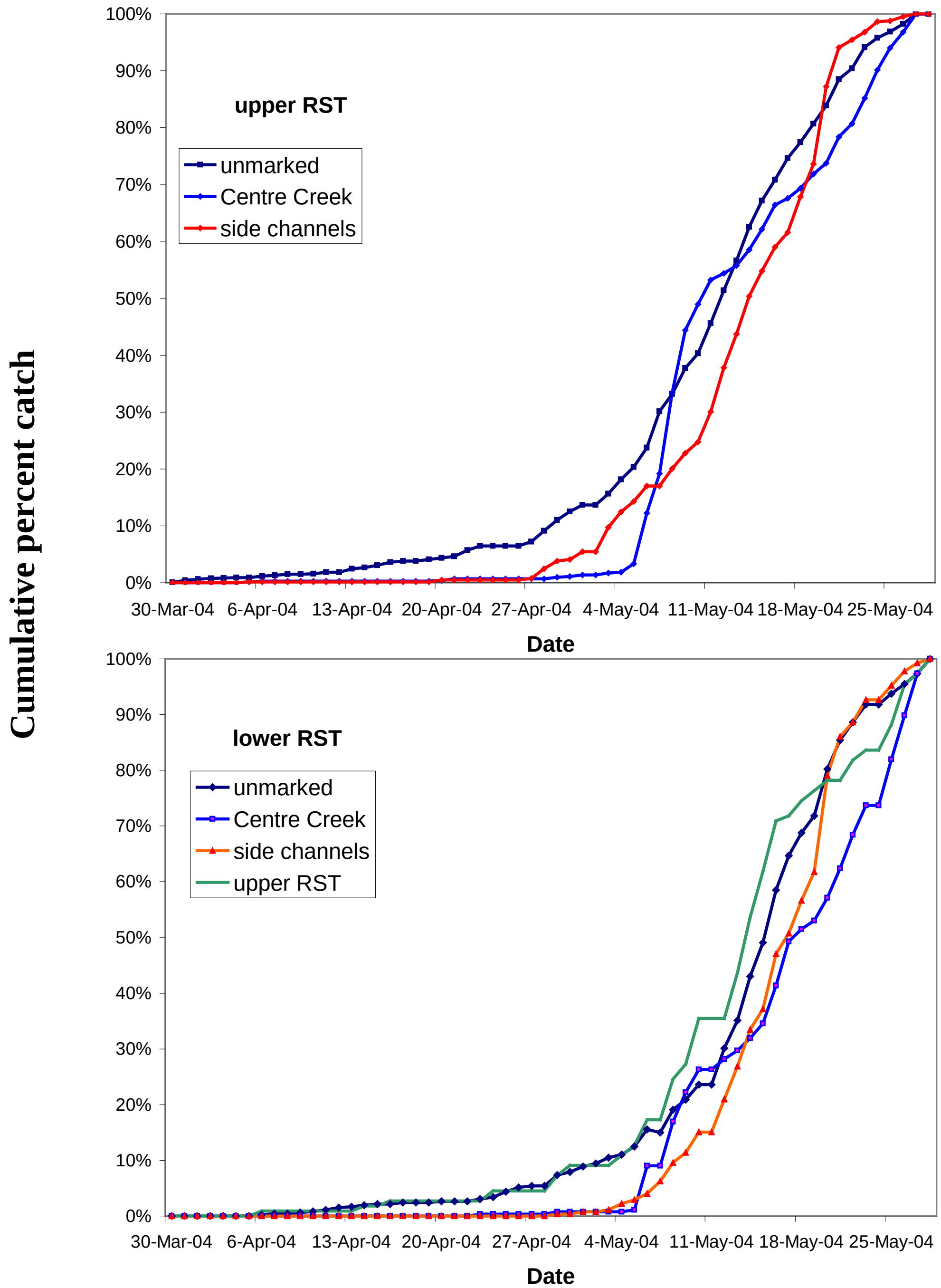

Fig. 4. Comparison of cumulative frequency distribution plots of catches, marked and unmarked smolts, in the upper and lower RSTs.

Appendix 1. Daily water temperatures (0C) at the constructed channels, Centre Creek and the RST sites.

Date	Weyerhaeuser channel	Nature Trust channel	Centre Creek	Mainstem LRST	Mainstem URST
30-Mar			8.5		8
31-Mar					
01-Apr	5				4.5
02-Apr	5		7		
03-Apr	6.5		7		5
04-Apr	6.5				
05-Apr					
06-Apr	7	7	6		7
07-Apr					
08-Apr	7.5	7.5	8		
09-Apr			8	7	
10-Apr			8		7
11-Apr	8		7.5		7
12-Apr		9.5	9	8	8
13-Apr	8	9	10	7	6.5
14-Apr	7.5	9	8	7.5	7.5
15-Apr	8	9	8	7	7
16-Apr	8	9	8.5		7
17-Apr	8	7	7		6.5
18-Apr	8	9	8		
19-Apr		8		7	7
20-Apr	7.5	8	8	7	7
21-Apr		8	9	7	7
22-Apr	8.5	9	8	7.5	7.5
23-Apr	9.5	9.75	10	9	9
24-Apr		8.5	9	8	8
25-Apr	9	9	10	8	8
26-Apr	10	10	12	10	9
27-Apr		10	10	10	9.5
28-Apr	8.5	10	8	8	8
29-Apr	9.5	10.5	8.5	8.5	8.5
30-Apr	9	10	8.5	8.5	8.5
01-May		10.5	11	9.5	95
02-May	12	11	12	9.5	9.5
03-May	10	11	10	10	9.5
04-May		11	10.5	9.5	9
05-May	9	10	11	10	10
06-May	9	10	11	8	8
07-May	10	10.5	11	9	9.5
08-May		11.5	8.5	9	9.5
09-May	10	12	10	10.5	10.5
10-May		11	11	10	10
11-May	10	11	12	9	9
12-May		11	13	9.5	10
13-May	11	12	13	10	10
14-May		12	13	10	10

15-May	11	12	11	11	11

Appendix 1. cont'd

Date	Weyerhaeuser channel	Nature Trust channel	Centre Creek	Mainstem LRST	Mainstem URST
16-May		12	13	11	11
17-May	11	12	13	10	10
18-May		12.5	13.5	11	11
19-May	13	12.5	14	12	12
20-May		13.5	13	11.5	13
21-May	13	13	13.5	12.5	12.5
22-May		13	12	12	12
23-May	12	13	14	11	11
24-May		12	13	11	11
25-May	12.5	13	12.5	12.5	12.5
26-May	12	12	12.5	11.5	12
27-May			12	12	12
28-May			12	11.5	

Appendix 2. Summary of mean fork length (mm) of juvenile coho by site and collection period.

Period 1 30 Mar – 29 April

Site	mean FL	range	SE	n
CC	80.3	60 - 138	0.65	312
LR	92.4	65 - 170	1.74	90
NT	83.6	58 - 125	0.54	438
UR	89.2	62 - 124	0.68	317
WEY	81.6	63 - 110	0.73	137

Period 2 30 April – 11 May

Site	mean FL	range	SE	n
CC	84.6	62 - 126	0.33	945
LR	95.9	71 - 128	0.57	295
NT	90.4	62 - 128	0.35	1286
UR	94.0	64 - 134	0.36	847
WEY	86.1	68 - 118	0.82	133

Period 3 12 May – 19 May

Site	mean FL	range	SE	n
CC	83.3	66 - 111	0.39	398
LR	96.5	71 - 141	0.43	530
NT	92.6	68 - 129	0.60	400
UR	92.5	70 - 125	0.41	515
WEY	88.8	71 - 117	0.77	141

Period 4 20 May – 28 May

Site	mean FL	range	SE	n
CC	83.1	69 - 112	0.57	183
LR	95.1	71 - 143	0.45	426
NT	95.0	68 - 136	0.59	451
UR	92.7	70 - 122	0.42	459
WEY	86.9	68 - 111	0.83	118

All Periods

Site	mean FL	range	SE	n
CC	83.42	60 - 138	0.23	1838
LR	95.66	65 - 170	0.28	1341
NT	90.36	58 - 136	0.25	2575
UR	92.61	62 - 134	0.22	2138
WEY	85.82	63 - 118	0.41	529