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THE CONTRIBUTION OF TWO CONSTRUCTED SIDE-CHANNELS TO COHO SALMON SMOLT PRODUCTION IN THE ENGLISHMAN RIVER

by

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In 1992 and 1989-98, two side-channels were constructed in the Englishman River to increase off-channel rearing habitat for juvenile coho salmon. In 1998, 1999 and 2001, the numbers of coho smolt outmigrating from these channels and from the mainstem/tributary area were monitored to assess the contribution of restored habitat to overall smolt production in the Englishman River system.

For 1998, 1999 and 2001, respectively, the mean density of outmigrating coho smolts was 5.2, 2.4 and 3.1 times greater for the side-channel area compared to the mainstem/tributary area. While the side-channels accounted for less than 8% of total stream (by channel length), smolt outmigrants from the channels represented 25% of the estimated total smolt production for the system in 1998, 15% in 1999 and 19% in 2001 (8,339 smolts of 33,531 ? 10,605 in 1998, 7,695 smolts of 50,622 ? 5,873 in 1999 and 5,893 smolts of 31,005 ? 1,127 in 2001).

The use of mark-recapture methodology and rotary screw traps (RSTs) was an effective means of estimating smolt numbers for the mainstem/tributary area of the Englishman River (95% CI ranged from ? 4% to 32% of the estimates). During 1998, smolt population estimates obtained using the standard Petersen estimator were similar to those computed using a maximum likelihood estimator and temporally stratified data. This was despite the fact that the assumptions of constant proportions of marked to unmarked fish and constant capture efficiency over time were not met.

During all three years of the study, smolt population estimates for the mainstem/tributary area appeared to be most sensitive to violation of the assumption of equal catchability for marked and unmarked smolts. In 1998 and 1999, lower capture efficiency for marked smolts from the side-channels compared to that for a subsample of marked smolts from the mainstem/tributary suggested that capture efficiency may have been higher for unmarked mainstem/tributary smolts compared to marked side-channel smolts. However, this was uncertain as recapture numbers for marked mainstem/tributary smolt were very low. In 2001, when the number of recaptures were relatively high for all mark groups, capture efficiency among groups was generally consistent.

Keywords: stratified populations, mark recapture, downstream trapping, fish marking

RÉSUMÉ

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Mots clés:

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~ This study is in memory of Paul Adams for his hard work and dedication to the fisheries resource. ~

1.0 INTRODUCTION

In southwestern British Columbia (B.C.), juvenile coho generally spend one, but sometimes two years in fresh water before migrating to sea as smolts (Bradford et al. 1996). Freshwater production appears to be limited by survival during the winter (Hartman et al. 1996; Solazzi et al. 2000), and there is considerable evidence to suggest that overwinter survival is influenced by habitat quality (Nickelson et al. 1992; Quinn and Peterson 1996). Hartman et al. (1996) found that biological and physical interactions affected survival rates at all life stages, but the availability and quality of winter habitat was the crucial factor affecting overall smolt carrying capacity.

Over the last two decades, the importance of off-channel habitat (e.g., riverine ponds, ephemeral tributaries, wetlands, groundwater-fed tributaries) in providing refuge from adverse conditions in mainstem habitats and streams during the winter has been recognized (see Cunjak 1996 for a review). Sharma and Hillborn (2001) recently showed that variation in coho smolt production among 14 streams in western Washington could be explained in part by the amount of off-channel habitat (ponds) available in each stream. Accordingly, construction of off-channel habitat has been a major component of watershed restoration programs in B.C. and the U.S. Pacific Northwest (Peterson 1985; Sheng et al. 1990; Lister and Finnigan 1997). In many streams, the use of both mainstem and off-channel habitat by overwintering coho may act to stabilize freshwater production because poor survival in one type of habitat is often balanced by relatively high survival in the other (Brown and Hartman 1988; Lestelle et al. 1993).

Construction of side-channels and ponds may be a more effective restoration technique compared to placement of structures in stream channels. This is because side-channels and ponds are less prone to failure in destabilized, high energy coastal watersheds (Frissell and Nawa 1992; Reeves et al. 1991). Moreover, coho may prefer off-channel habitat to mainstem habitat, providing the off-channel habitat is structurally complex (Brown 1985).

Examined in isolation, artificial side-channels and off-channel ponds have been shown to support relatively high densities of overwintering juvenile coho (Peterson 1985; King and Young 1986; Swales and Levings 1987; Koning and Keeley 1997). However, few studies have considered the overall effect of off-channel habitat restoration on smolt production in a stream (Lestelle et al. 1993; Decker and Lewis 2000; Decker et al. in press). In most cases, it is uncertain whether enhancement has increased carrying capacity of the system, or merely shifted fish production away from the existing natural habitat (Riley and Fausch 1995; Keeley and Walters 1996.

Since the early 1980s, concern has been voiced about declining returns of coho salmon and other anadromous species to the Englishman River (Hurst 1988). In 1988, Fisheries and Oceans Canada (DFO) began working to rehabilitate coho salmon and other salmonid populations in the Englishman River through hatchery enhancement and habitat restoration. A major initiative for coho was the construction of two side-channels to provide off-channel spawning and rearing habitat.

During the spring seaward migration of 1998,1999, and 2001, we monitored the numbers of coho smolt outmigrants from the two side-channels and from the mainstem/tributary area of the Englishman River. Our primary objective was to assess the contribution of the two side-channels to overall smolt production in the system. Our secondary objective was to examine the utility and problems associated with the use of a stratified mark-recapture sampling design to estimate numbers of migrating smolts. This is particularly relevant to stock assessment work in larger streams where the use of full-span downstream weirs is not possible. This report presents results from all three study years.

1.1 Background

The Englishman River is situated southwest of the City of Parksville on Vancouver Island (Figure 1 inset). It flows in a north-easterly direction from Mount Arrowsmith and discharges into the Strait of Georgia north of Craig Bay. Mean annual precipitation is 964 mm of which 15% occurs during summer months. Currently, most of the watershed is privately owned and managed for timber production. There is some residential development in the lower river and estuary. An intake in the lower river provides drinking water to an expanding community.

The river is about 28 km in length and drains a watershed area of 324 km^2. Mean annual discharge during 1980 to 1998 was 13.8 cms, with observed maximum and minimum discharges of 454 cms and 0.1 cms, respectively (Water Survey of Canada, unpublished data).

The Englishman River Falls, located approximately 16 km upstream of the mouth, creates a natural migration barrier to all anadromous fish. The main tributaries contributing to anadromous fish habitat are the South Englishman River (4.5 km of accessible habitat), Centre Creek (5.2 km accessible), Morison Creek (2.1 km accessible) and Shelley Creek (3.0 km accessible), for a total anadromous habitat in the watershed of 31 km. There are seven small lakes in the upper watershed, with elevations ranging from 110 to 450 m, but these are not accessible to anadromous fish. The lower 8 km of the Englishman River and the accessible portions of the tributaries are low gradient (< 2%), and provide the majority of juvenile salmonid habitat.

Approximately 90% of the land base in the Englishman watershed has been logged, mostly during the past 50 years, and the watershed is now dominated by second growth coniferous forest (J. Eden, pers. comm.). About 50% of the second-growth portion of the watershed (mostly lower valleys) is over 20 years old, and much of this is 50 years or older. The upper watershed areas are in the early stages of regeneration (<20 years old).

The riparian zone of the Englishman River is dominated by 40- to 60-year old mixed stands of red alder (*Alnus rubra)*, big-leaf maple (*Acer macrophylum)*, western hemlock (*Tsuga heterophylum*), Douglas fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata)*. Reduced forest cover and extensive road-building have led to slope instability, landslides, altered run-off patterns and sediment loading in the stream channels. This has resulted in low summer flows, winter flooding, unstable channels and loss of riparian cover. In addition, in-stream large woody debris and naturally occurring off-channel habitat are relatively scarce (G. Stewart, pers. comm.).

The Englishman River sustains runs of chum *(Oncorhynchus keta)* and coho salmon *(O. kisutch*), as well as smaller runs of chinook *(O. tshawytscha)*, pink *(O. gorbuscha)*, sockeye *(O. nerka)*, steelhead *(O. mykiss)* and anadromous cutthroat trout *(O. clarki)* (Anon, 1987; Brown et al. 1977). Resident rainbow and cutthroat trout are also present in the system (Boom and Bryden 1993). Historically, fish stocks in the Englishman River have contributed to commercial, sport and native fisheries on the south coast of B.C. (Hamilton 1982; R. Axford, pers. comm.), but the majority of salmonid populations in this river are currently depressed. As with many east coast Vancouver Island streams, clear-cut logging, overfishing, urbanization, and in recent years, poor ocean survival, have all contributed to reduced productivity.

During 1988-1995, natural recruitment was augmented by releases of hatchery fry into known spawning and rearing areas of the watershed, but no fry or smolts were released during 1996-2001 (R. Cook, DFO, unpubl. data; G. Stewart, pers. comm.). Therefore, during the three study years, coho smolt production was dependent entirely on natural recruitment.

Adult coho migrate into the Englishman River starting in late September; spawning peaks in mid-November and continues until January. Spawning occurs throughout the system, but is concentrated in a 3 km long reach downstream of Morison Creek (Hamilton and Kosakoski 1982). Coho escapements were estimated by visual observation from 1953 until 1998 (SEDS database, DFO, unpublished data). These estimates are qualitative because average spawner residence time and observer efficiency were not considered, and observers and methods varied over the years. From 1999 to 2001, a more intensive spawner survey was conducted utilizing diver counts rather than shore counts. Area-under-the-curve (AUC) methodology (Irvine et al. 1992) was used to estimate escapements based on estimates of spawner residence time and diver efficiency for similar Vancouver Island streams. Synchronous with a coast-wide trend (Simpson et al. 2000), visual observations suggest that escapements to the Englishman River declined considerably during the 1980-90s, but increased substantially beginning in 1998 in response to reduced exploitation in marine fisheries (Figure 3). Estimated escapements for the two brood years (1996, 1997) that correspond to smolt abundance during the first two years of this study (1998, 1999) were among the lowest on record. The AUC spawner estimate for 1999 (2,978 adults) which corresponds to smolt numbers in the 2001 study year, was among the highest on record.

1.2 Habitat restoration

In 1988, the Habitat and Enhancement Branch of DFO implemented the first phase of the Englishman River Salmon Maintenance Plan. The objective was to create new off-channel habitat as a means of offsetting losses of natural habitat. As part of this plan, DFO, with support from Fletcher Challenge Ltd. (now Timber West Forest Products Ltd.) and MacMillan Bloedel Ltd. (now Weyerhaeuser Ltd.), constructed two side-channels to provide spawning, rearing and overwintering habitat, primarily for coho salmon.

The channels are located on the lower Englishman River (Figure 1), with the Timber West Channel on the north (left) bank, approximately 7 km upstream from the estuary and just below the Morison Creek confluence, and the Weyerhaeuser Channel about 1 km downstream of that site, on the south (right) bank.

The Timber West Channel was constructed in 1992. It is approximately 1,380 m long, and provides about 11,421 m^2 of side-channel habitat interspersed with 6,288 m^2 of pond habitat, for a total wetted area of 17,709 m^2. This channel consists of a river intake, a small settling pond and a 380 m rearing channel. It drains into a small natural pond-channel complex, then into the Englishman River. Gravel was placed in riffle portions of the channel to enhance spawning habitat, and large woody debris was added to the upper 200 m to provide cover. A sketch of the Timber West Channel is provided in Appendix 1.

The original Weyerhaeuser Channel was constructed in 1989, and consisted of a 600 m long groundwater-fed channel with a wetted area of approximately 4,000 m^2. In March 1997, a mark-recapture study conducted in the channel yielded an estimate of 0.3 coho pre-smolts$\cdot m^{-2}$ (Millar 1997). It was thought that higher pre-smolt densities could be achieved with greater flows and habitat complexity. In September 1998, improvements were made to this site, including installation of a surface water intake and addition of large woody debris. Also, a new channel section was added, leading from the river intake into the old channel, and two shorter, blind channels were constructed (Appendix 2). As a result of this expansion, the channel length was increased to 950 m and the wetted area to 6,000 m^2.

The above side-channels were created by excavating portions of the floodplain parallel to the river mainstem, and are protected from mainstem flooding by set-back dykes. Flow is derived from groundwater upwelling and from controlled surface water diversions from the mainstem. The channel portion of each site resembles a small, low gradient (0.5%) stream. The channels consist of roughly 80% rearing (pool) and 20% spawning (riffle) habitat. Wetted channel width ranges from 2.5 m to 20 m, and channel depth from 20 cm to 60 cm. Pool depth ranges from 0.5 m to 1.5 m. Discharge is low (< 1 cms) and relatively stable year-round. Channel substrate is composed of either native or introduced gravels (size range: 2-10 cm).

2.0 METHODS

2.1 Side-channel population estimates

In 1998, 1999 and 2001, coho outmigrants from the Weyerhaeuser and Timber West channels were enumerated at converging downstream weir fish traps (Conlin and Tutty 1979). The downstream weirs consisted of 1 m x 2.5 m wooden panels screened with 0.5 cm square galvanized wire mesh, 15 cm diameter plastic entrance pipes, and welded aluminum trap boxes with screened sides. Additional mesh panels were installed in the intake structure at the upstream end of each channel to force outmigrating smolts to enter the downstream trap at the channel outlet.

In 1998, the Weyerhaeuser weir was installed about 30 m above the channel outlet, adjacent to a footbridge (Appendix 2), while the Timber West weir was installed 100 m above the channel outlet (Appendix 1). In 1999 and 2001, the Weyerhaeuser weir was moved further upstream (about 250 m above channel outlet) to avoid backwatering during peak flow events. To adjust for the number of channel smolts below each weir, the number of smolts captured at each channel weir were expanded by the ratio of the total wetted channel area (m^2) to the channel area above the weir (see below).

Channel weir	Year	Expansion	Ratio
Timber West	All years	17,709/16,513 m^2	1.07
Weyerhaeuser	1998	4,000/3,810 m^2	1.05
	1999, 2001	6,000/4,605 m^2	1.30

The weirs were operated daily from April to June (see below). Each day, the weirs were thoroughly cleaned, inspected for damage and repaired if necessary. Water temperatures and discharge (staff gauge) were also recorded daily.

Channel weir	1998	1999	2001
Timber West	April 15 - June 10	April 22 – June 13	April 18 - June 13
Weyerhaeuser	April 20 - June 10	April 28 – June 13	April 18 - June 12

All captured fish were identified to species, counted and measured for fork length (to nearest mm). During 1998 and 1999, fish greater than 79 mm were considered to be smolts and marked (see Section 2.2.1), while smaller fish were assumed to be yearling parr that would not smolt until the following spring, and were not marked. This criterion was based on the observation that fish smaller than 79 mm generally did not exhibit physical characteristics typical of smolts. However, in 2001 the majority of coho less than 79 mm in length also exhibited smolt characteristics, and a minimum length of 70 mm was used to distinguish smolts from parr. Accordingly, the term "smolt" used in this report refers to those coho greater than 79 mm for the 1998 and 1999 study results, and greater than 70 mm for the 2001 study results.

2.2 Englishman River population estimates

2.2.1 Marked populations

To generate mark-recapture estimates of total smolt abundance for the Englishman River system, coho smolts captured in the side-channel weirs were marked prior to release (fish from mainstem and tributaries served as the unmarked population). Marking consisted of applying a sub-dermal tattoo at one of several fin locations. Tattoo marks were applied with a Pan-Jet dental inoculator using Alcian Blue dye (Herbinger et al. 1990). In 1998, smolts were differentially batch-marked by week (7 weeks) to facilitate the use of a stratified mark-recapture estimator (see Section 2.2.3) and by site (different marks for each side-channel). In 1999, smolts were marked according to site only. As well, to increase the marked population, additional channel smolts were captured in the 250 m section of Weyerhaeuser Channel downstream of the weir (Figure 2-site b, Appendix 2); six to ten minnow traps were set daily in that segment, and all unmarked smolts were marked. In 2001, smolts from the two side-channels were given the same mark. That year, the program was expanded to include smolts emigrating from Centre Creek, a small tributary (5.2 km of accessible length) to the lower Englishman River (Figure 1). A full-span downstream weir was installed in Centre Creek just upstream of its confluence with the Englishman River, and all captured smolts received a unique mark.

2.2.2 Recovery of marked fish

In 1998, the total abundance of coho smolts in the Englishman River system was estimated using the numbers of marked (side-channel) and unmarked (mainstem/tributary) fish captured in a 2.0 m diameter rotary screw trap (RST) (Thedinga et al. 1994) operated in the lower mainstem. The trap was installed on the left (west) river bank, adjacent to Perry's RV Park, about 1.9 km above the tidewater (Figure 2). In 1999, two RSTs were operated at this location to increase catch numbers (Figure 2).

Two RSTs were also operated in 2001, with RST 1 installed at the same location as in the previous years (Perry's) and RST 2 installed upstream, 4 km from the tidewater (Figure 2). This allowed previously unmarked mainstem/tributary smolts to be captured, marked and released at RST 2, then recovered at RST 1 downstream. This provided mark-recapture data for a mainstem mark group independent of the side-channel and Centre Creek mark groups. The operating schedule for the RSTs during each year was as follows:

Mainstem trap	1998	1999	2001
RST 1	April 21 - June 10	May 15 - June 13 *	April 18 - June 13
RST 2	--	April 30 - June 13	April 24 - June 12

* Trap unavailable before May 15, 1999.

The RST(s) were sampled twice daily, and cleaned and repaired as necessary. All captured fish were identified to species and counted. Coho juveniles were enumerated, measured for fork-length (nearest mm), examined for marks and released downstream. River and side-channel water temperatures were recorded daily by the crew, and are shown in Appendix 3. Records of daily discharge were obtained from the Water Survey of Canada (Station 08HB002) and are graphed in Appendix 4.

2.2.3 Population estimates and tests of mark-recapture assumptions

All population statistics were generated using the statistical software package SPAS (stratified population analysis system) which is available for public use (http//www.cs.umanitoba.ca/~popan/, see Arnason et al. 1996). As a first step, we computed for the portion of the Englishman River system upstream of RST 1 (including side-channels), the estimated total smolt abundance and the corresponding 95%

confidence intervals, using the single mark-recapture or "pooled Petersen estimator" (PPE) (Ricker 1975, p. 78):

$$N_1 = (M+1)(C+1) / (R+1) \qquad (1.1)$$

$$Var(N_1) = N_1^2(C-R) / (C+1)(R+2) \qquad (1.2)$$

$$95\%\ CI\ (N_1) = ?\ 1.96\ ?\ Var\ (N_1) \qquad (1.3)$$

where:

M = number of marked smolts released from two side-channels
C = number of marked and unmarked smolts recovered at the RST(s)
R = number of marked side-channel smolts recovered at the RST(s)

To estimate the number of smolts for the entire 31.0 km of anadromous habitat in the Cheakamus River system excluding artificial side-channels:

$$N_{main/trib} = (N_1 - N_{side\text{-}channel})\ ?\ L_{total} / L_{upstream} \qquad (1.4)$$

$$95\%\ CI\ (N_{main/trib}) = 95\%\ CI\ (N_1)\ ?\ L_{total} / L_{upstream} \qquad (1.5)$$

where:

L_{total} = total anadromous length of the Englishman River mainstem and tributaries (31.0 km)
$L_{upstream}$ = total length of the Englishman River mainstem and tributaries upstream of the RSTs (29.1 km)

To estimate the number of smolts for entire the Englishman River system including artificial side-channels:

$$N_{total} = N_{main/trib} + N_{side\text{-}channel} \qquad (1.6)$$

$$95\%\ CI\ (N_{total}) = 95\%\ CI\ (N_{main/trib}) \qquad (1.7)$$

*For the 1998 and 1999 study years, *M* includes only smolts marked and released from the weirs in the two side-channels. For 2001, *M* includes marked smolts from the side-channels, Centre Creek, and RST 2.

Seber (1982) noted that the PPE may not be appropriate for migrating populations, particularly if the following assumptions are not met: population closure (i.e., sampling period covers most of the smolt outmigration period), constant proportions of marked to unmarked individuals in recovery catches, constant capture efficiency over time, negligible mark-loss, and equal capture efficiency for marked and unmarked individuals. These assumptions are addressed below.

To examine whether failure to meet the first three assumptions, we also computed for the 1998 data, stratified population estimates using a maximum likelihood estimator developed by Darroch (1961) and modified by Plante (1990). This estimator allows population estimates to be computed based on summed estimates for individual release or recovery strata. Prior to applying the Darroch estimator to the data, we pooled or excluded individual strata in cases where numbers of fish marked or recaptured were very low, as recommended by Arnason et al. (1996). A goodness of fit test (Arnason et al. 1996) was used to examine how well the Darroch model fit the data.

Population closure: We tested the assumption of population closure by plotting for each year, the histograms of daily catch totals at the RST(s) over time, and for each year, comparing daily numbers of smolts captured at the beginning and end of the trapping period to the numbers captured during the migration peak.

Constant proportions of marked to unmarked recoveries over time: To test this assumption, the RST recovery catches for each year were stratified into seven temporal periods (see Table 3a), and the proportion of marked to unmarked smolts among temporal strata were compared (chi-square; Arnason et al. 1996).

Constant capture efficiency over time: As stated earlier, coho outmigranting from the side-channels in 1998 were captured at the weirs and differentially marked each week prior to release in order to establish temporally stratified release periods (see Table 3a). For the 1998 data, capture efficiency (the percentage of smolts from each temporal mark group recovered at the RST) was compared for the weekly releases (chi-square; Arnason et al. 1996). The 1999 and 2001 catch data were stratified by marking site and recovery period only (see Table 3b-d). That is, fish were not differentially marked by release period as was done in 1998 because 1) PPE and stratified mark-recapture population estimates for the 1998 data differed only marginally, and 2) results from 1998 suggested that release site for marked fish was a more important source of bias than marking date.

Mark loss and marking-induced mortality: Potential mark loss and marking-induced mortality were not assessed in this study. In two similar studies, Decker (1998) and Decker and Lewis (1999) observed that for hatchery coho smolts held in enclosures for 50 days, the estimated Pan-jet tattoo retention rates were 99% and 96%, respectively. Decker and Lewis (1999) also found that mortality was negligible during a 24-hour period following marking. Therefore, for this study, we assumed a mark retention rate of 100% and a marking-induced mortality rate of 0%.

Equal capture efficiency for marked side-channel smolts and "unmarked" mainstem/tributary smolts: We tested this assumption indirectly by comparing RST capture efficiency for marked side-channel smolts and uniquely marked smolts from the mainstem/tributary area. In 1998, a unique mark (tattoo) was applied to a randomly selected portion (5%-10%) of the mainstem coho greater than 79 mm, from each week's catch at RST 1. These fish were held overnight, then released at a mid-stream location in the mainstem, 500 m above RST 1 (Figure 2 - site a).

In 1999, mainstem smolts were minnow-trapped in the Englishman River just upstream of the Weyerhaeuser Channel site (Figure 2 - site c) during the same period that the two downstream RSTs were in operation. About 25 minnow traps were fished daily, and the captured coho were sampled in a similar manner as those trapped at the RSTs below. Minnow-trapped coho larger than 79 mm, were uniquely marked and released immediately, 100 m below the capture site.

In 2001, mainstem/tributary smolts captured at the upper RST 2 were given a unique mark and released for recapture at RST 1 downstream. That year, capture efficiency was also estimated for the uniquely marked smolts from Centre Creek. That is, capture efficiency at RST 1 could be compared for smolts migrating from the side-channels, Centre Creek and mainstem/tributary area; and capture efficiency at the RST 2 could be compared for smolts from the side-channels and Centre Creek.

To examine the potential effects of unequal capture efficiency for marked / unmarked smolts on population estimates, we computed, wherever possible, independent PPE estimates of total smolt abundance using individual groups of marked smolts. For each of 1998 and 1999, three separate PPE estimates were computed using three mark groups (Timber West Channel, Weyerhaeuser Channel and mainstem/tributary area), along with the RST recovery data. For 2001, five separate PPE estimates were computed: three estimates were based on RST 1 recovery data for the side-channel, Centre Creek and mainstem/tributary mark groups, respectively, and two estimates were based on RST 2 recovery data for the side-channel and Centre Creek mark groups, respectively.

<u>Effect of fish body size on capture efficiency</u>: One possible cause for unequal capture efficiency at the RSTs for marked and unmarked fish is size difference. If capture efficiency is size dependent, and marked smolts differ in size from unmarked smolts, this could lead to unequal capture efficiency (Ricker 1975). To examine whether differences in body size biased the mark-recapture data, we first tested whether mean fork length differed for marked smolts from the release sites and unmarked smolts from the mainstem/tributary area (Bonferroni-adjusted, multiple t-tests). To correct for unequal samples sizes of smolt length for different weeks during smolt migration, mean fork length for a particular site was computed as the weighted mean of weekly averages (Sokal and Rohlf 1981, p. 178). That is, the weighting factor was the number of smolts captured at that site each week. If a significant difference in mean length was detected, we then tested for size-dependent capture efficiency: for each mark group, the mean fork length of smolts sampled at the release site was compared to that for smolts from the same mark group that were recaptured at the recovery site (Bonferroni-adjusted, t-test).

3.0 RESULTS

3.1 Constructed side-channels and Centre Creek

In 1998, the numbers of juvenile coho captured at the Weyerhaeuser and Timber West channel weirs were 788 and 7,552, respectively. Of these, 778 (99%) and 7,014 (93%), were considered to be ‘smolts’ (fork length > 79 mm) and marked prior to release. When the estimated smolt abundance in the channel segments below the weirs was included, the overall numbers of outmigrants totaled 817 and 7,522 for the Weyerhaeuser and Timber West channels, respectively (or 1,362 and 5,451 smolts?km^{-1}) (Table 1).

In 1999, the numbers of juvenile coho captured at the Weyerhaeuser and Timber West channel weirs were 2,962 and 3,944, respectively. Of these, 2,899 (98%) and 3,653 (92%) were larger than 79 mm. When the estimated smolt abundance in the channel segments below the weirs was included, the overall numbers of outmigrants totaled 3,777 and 3,918, for the Weyerhaeuser and Timber West channels, respectively (or 3,976 and 2,839 smolts?km^{-1}) (Table 1).

In 2001, the numbers of juvenile coho captured at the Weyerhaeuser and Timber West channel weirs were 1,582 and 3,608, respectively. Of these, 1,582 (100%) and 3,573 (99%) were considered to be 'smolts' (fork length > 70 mm). When the estimated smolt abundance in the channel segments below the weirs was included, the overall numbers of outmigrants totaled 2,061 and 3,832 for the Weyerhaeuser and Timber West channels, respectively (or 2,170 and 2,777 smolts?km^{-1}) (Table 1). In 2001, an additional 3,842 juvenile coho were captured at the downstream weir in Centre Creek. Of these, 3,828 (99.6%) were greater than 70 mm in length, for an estimated smolt density of 736 smolts?km^{-1} in the 5.2 km of accessible habitat in that creek (Table 1).

For each side-channel, peak outmigration shifted from earlier May in 1998 to later May and early June in 1999 and 2001 (Figures 4-6 a,b). Temperatures were lower and mean discharges, higher in 1999 compared to 1998 and 2001. Peak outmigration from Centre Creek occurred during the third week of May in 2001 (Figure 6e). No incidence of weir failure was reported during the study.

For all three study years, the assumption of population closure for channel data appeared to be met. This was based on the shapes of daily catch histograms which suggested that the vast majority of coho smolts outmigrated from the channels during the period of channel weir operation (Figures 4-6 a,b). Therefore, it could be assumed that the total catches of smolts at each channel weir gave a reasonable estimate of overall channel outmigrants, taking into account the adjustments applied to correct for channel smolts below the weirs. Also for Centre Creek, the shape of the daily catch histogram suggested that total catch at that weir gave a reasonable estimate of overall creek outmigrants (Figure 6e). For all study years, the observed mortality for coho smolts was less than 1% at each weir.

Other species captured at the channel weirs and in Centre Creek included chinook, chum, steelhead and resident rainbow trout, cutthroat trout, sculpins (*Cottus spp.*), three-spine stickleback (*Gasterosteus aculeatus*) and lamprey (*Lampetra spp.)*.

3.2 Englishman River mainstem and tributaries

During the study periods in 1998, 1999 and 2001, daily water temperatures in the Englishman River mainstem ranged from 5?C to 15?C (Appendix 3), while discharge ranged from 3 cms to 40 cms (Appendix 4).

In 1998, a total of 7,792 coho smolts were batch-marked by sampling period and released at the two side-channel weirs (Table 2). At the mainstem recovery site downstream, a total of 545 smolts (130 marked side-channel and 415 unmarked mainstem/tributary coho) were captured in RST 1 (Table 2). The PPE estimate of the number of coho smolts for the 29.1 km long section of the Englishman River system upstream of RST 1 (including side-channel fish) was 32,481 (95% CI: ? 4,831). When this estimate was extrapolated to include the 1.9 km mainstem reach downstream of RST 1, the total number of coho smolts for the Englishman River system in 1998 was 34,578 (95% CI: ? 5,143; Table 1).

The PPE estimate of smolt abundance in 1998 may have biased because the assumptions of constant proportions of marked to unmarked recoveries and constant RST capture efficiency over time were not met (see pages 12,13). Because the 1998 data were temporally stratified by marking and recovery periods, the Darroch estimator could be used to address the failure to meet these assumptions (Arnason et al. 1996). Based on data stratified by release and recovery period, the Darroch estimate of total coho smolts for the system in 1998 (including side-channels and the 1.9 km mainstem reach below RST 1) was 33,531 ? 10,605, which is similar to the PPE estimate (34,578 ? 5,143; Table 1). For the Darroch estimate, we pooled release strata 1-2 and recovery strata 1-2 and 5-7, because release stratum 1 comprised only 37 fish, and total catches for recovery strata 1, 5 and 7 were low compared to other recovery periods (see Arnason et al. 1996 for a rationale regarding the pooling of release and recovery strata). As well, we excluded the final release stratum (release stratum 7) because none of the fish from this mark group were recovered, and because stratum 7 represented only 2% of the total marked population (Table 3a). The low, non-significant G^2 value associated with the Darroch estimate (G^2 = 3.25, df = 1, P = 0.07) indicated an acceptable fit to the data. Subtracting the estimated smolt numbers for the side-channels (8,339) from the Darroch estimate for the system, gave an estimate of 25,192 ? 10,605 (813 smolts?km^{-1}) for the 31 km of mainstem and tributary habitat (Table 1).

In 1999, a total of 6,862 coho smolts were marked and released at the two side-channel weirs (Table 2). Of this total, the Weyerhaeuser channel portion (3,209) included 310 smolts that were minnow-trapped and marked in the 250 m channel segment below the weir. At RST 1 in the lower mainstem, 222 of the marked channel smolts and 1,330 unmarked smolts were recaptured. At RST 2, an additional 31 marked and 108 unmarked smolts were captured. Given the low number of smolts captured at RST 2, population statistics were computed for pooled data from the two RSTs (Table 2). The PPE estimate of the number of coho smolts for the Englishman River system upstream of RST 1 (including side-channel fish) was 47,591 (95% CI: ? 5,513). When this estimate was extrapolated to include the portion of the mainstem downstream of RST 1, the total number of coho smolts for the system in 1999 was 50,622 (? 5,873; Table 1). Subtracting from this total the estimated number from the side-channels (7,695), gave a smolt estimate for the mainstem/tributary area of 42,927 (? 5,873) or 1,385 smolts?km^{-1} (Table 1).

In 2001, a total of 8,416 marked coho smolts were released from the two side-channels and from the weir at Centre Creek (5,128 and 3,288 smolts, respectively, Table 2). In the mainstem, a total of 873 marked and 2,500 unmarked smolts were captured at RST 2 (Table 2), and of these unmarked smolts, 2,143 were marked prior to release. At RST 1 downstream, captures consisted of 1,854 smolts from the three mark groups (side-channels, Centre Creek and mainstem RST 2) and 3,281 unmarked smolts from the mainstem/tributary area (Table 2).

Based on the above 2001 recovery data for RST 1, the PPE estimate of the number of coho smolts for the portion of the Englishman River system upstream of RST 1 (including side-channel fish) was 29,238 smolts (95% CI: ? 1,063). When this estimate was extrapolated for the mainstem section downstream of RST 1, the total number of coho smolts for the Englishman River system in 2001 was 31,005 (? 1,127; Table 1). Subtracting from this total the estimated number of smolts for the side-channels (5,893), gave a smolt estimate for the mainstem/tributary area of 25,112 (? 1,127) or 810 smolts?km^{-1} (Table 1).

<u>1988, 1999 and 2001 PPE estimates based on individual release strata</u>: Additional PPE estimates of total smolt abundance for the system were computed using individual data from each release site (Table 1). In 1998, mark-recapture data for the Timber West Channel produced a population estimate (32,620 ? 5,001 smolts) which was similar to the Darroch and PPE estimates for the system (33,531 ? 10,605 and 34,578 ? 5,143 smolts, respectively). In contrast, data for each of the Weyerhaeuser Channel and the mainstem minnow-traps produced high or low estimates for the system (64,685 ? 44,536 and 10,172 ? 5,987 smolts, respectively) compared to the Darroch estimate. These latter two estimates were based on total recaptures of 6 and 9 smolts, respectively (Table 2).

In 1999, mark-recapture data for each of the Weyerhaeuser and Timber West channels produced population estimates for the system of 48,657 ? 8,230 and 52,310 ? 8,594 smolts, respectively; these values were similar to the PPE estimate for the system (50,622 ? 5,873 smolts) (Table 1). The estimate derived from the mainstem minnow-trapping data was substantially lower (21,110 ? 11,402 smolts, total recaptures = 10; Tables 1,2).

In 2001, the pooled Peterson estimates for the total system based on data for individual mark groups (see Table 2), showed less variability compared to 1998 and 1999. For example, population estimates for the system in 2001 based on RST 1 recovery data for each of the side-channel and mainstem mark groups (29,436 ? 1,690 and 27,737 ? 2,536 smolts, respectively; Table 1), were similar to the PPE estimate based on all mark groups pooled (31,005 ? 1,127; Table 1). The PPE estimate based on RST 1 recovery data for the Centre Creek mark group was somewhat higher (36,783 ? 3,105 smolts), as were the PPE estimates based on RST 2 recovery data for each of the side-channel and Centre Creek mark groups (36,485 ? 2,821 and 37,531 ? 3,802 smolts, respectively; Table 1).

<u>Population closure for mainstem and tributaries</u>: In all three study years, the assumption of population closure appeared to be met for smolts migrating from the Englishman River. This was based on the shape of the daily catch histograms for the RSTs, which suggested that most smolts moved through the mainstem during the period of trap operation (Figures 4c, 5c,d, 6c,d).

Constant proportions of marked to unmarked recoveries: In all three study years, the proportion of marked to unmarked fish varied significantly over time during the migration period. In 1998, the proportion of marked smolts among the seven temporal recovery strata ranged from 5% to 46% (chi-square-test, df = 6, $X^2 = 66.42$, $P < 0.0001$; Table 3a), and in 1999, it ranged from 0% to 30% ($X^2 = 70.33$, $P < 0.0001$; Table 3b). In 2001, that proportion ranged at RST 1 from 0% to 38% ($X^2 = 91.13$, $P < 0.0001$) and at RST 2 from 0% to 39% (Table 3 c,d).

In 1998 and 1999, unmarked coho from the mainstem/tributary area migrated through the downstream recovery site earlier than did the marked side-channel fish (Figure 7 a,b). In these years, the marked channel coho contributed a greater proportion to the total RST catch during the second half of the sampling period (Table 3a,b). In 2001, the difference in migration timing for the marked and unmarked smolts was less pronounced (Figure 7c). When the 2001 data for RST 1 were re-tested with the first two recovery periods excluded (the remaining five periods accounted for 95% of the smolt catch at RST 1), the proportion of marked to unmarked fish did not differ significantly during May 5 - June 13 (range: 31%-38%, df = 4, $X^2 = 7.90$, $P = 0.10$; Table 3c). This was not the case for RST 2 catch data in 2001 where the proportion of marked smolts differed significantly among the recovery periods even when the first two periods were excluded (range: 22%-39%, df = 4, $X^2 = 21.30$, $P = 0.0003$; Table 3d).

Constant RST capture efficiency over time: The assumption of constant capture efficiency over time could only be tested for the 1998 data because smolts were not differentially marked by release period during subsequent study years. In 1998, capture efficiency at RST 1 varied significantly during the study period. Among the weekly release groups from the side-channels, the percentage of marked fish recovered at RST 1 ranged from 0%-3.3% (chi-square test, df = 6, $X^2 = 18.93$, $P = 0.004$), with no apparent trend of increasing or decreasing efficiency observed over time (Table 3a). Weekly capture efficiency was not correlated with water temperature or discharge ($R < 0.4$, $P > 0.05$ for both variables). When the 1998 data were re-tested with the first and last two release groups excluded (the remaining four groups accounted for 88% of the total number of marked smolts released), capture efficiency did not differ significantly during April 27 - May 24 (range: 1.3%-1.9%, df = 3, $X^2 = 1.98$, $P = 0.58$; Table 3a).

Equal capture efficiency for marked side-channel smolts and “unmarked” mainstem/tributary smolts: In 1998 and 1999, the assumption of equal capture efficiency for marked side-channel smolts and “unmarked” mainstem/tributary smolts was not met. During 1998, the “unmarked” mainstem group consisted of a portion of each week’s mainstem catch in RST 1 that was given a unique mark and released upstream (174 smolts in total). Of these, nine (5.2%) were recaptured in the RST below (Table 2). This percentage was higher than the mark recovery percentages for smolts released from the Timber West (1.8%) and Weyerhaeuser (0.8%) channels (chi-square, df = 2, $X^2 = 16.25$, $P = 0.0003$). In 1999, daily minnow-trapping in the mainstem above the Weyerhaeuser Channel resulted in the capture of 279 coho, of which 128 provided “unmarked” mainstem smolts (>79 mm) that were given a unique mark and released into the river. Of that group, 10 were recaptured at the RSTs below resulting in an RST capture efficiency of 7.8% (Table 2). This was significantly higher than the values obtained for marked smolts from the Weyerhaeuser (3.7%) and Timber West (3.4%) channels (df = 2, X^2 = 6.89, P = 0.03).

In 2001, capture efficiency at RST 1 did not differ significantly for marked smolts from the side-channels (18.5%) and from the mainstem/tributary area (19.6%) (chi-square, df = 1, X^2 = 1.22, P = 0.27; Table 2). Capture efficiency for the marked Centre Creek smolts (14.8%) was significantly lower compared to the other two mark groups (df = 2, X^2 = 26.74, P < 0.0001; Table 2). Capture efficiency at RST 2 was lower than at RST 1, but was not significantly different for the side-channel (10.5%) and Centre Creek smolts (10.2%; df = 1, X^2 = 0.20, P = 0.66; Table 2).

<u>Effect of fish body size on capture efficiency</u>: During all three study years, the mean fork lengths of marked smolts from the Weyerhaeuser and Timber West channels and unmarked smolts from the mainstem/tributary area were similar (Bonferroni-adjusted multiple t-tests, P > 0.006 for all cases; Table 4). In 2001, smolts captured in Centre Creek were significantly smaller (82 mm) than smolts from the side-channels (87 mm) and smolts from the mainstem/tributary area captured at RST 1 and RST 2 (91 mm and 87 mm, respectively, P < 0.006 for all cases; Table 4). Smolts captured in Centre Creek were also significantly smaller than marked smolts from Centre Creek that were recaptured at both RST 1 (89 mm) and RST 2 (89 mm; P < 0.017 for both cases).

During all study years, the proportion of smolts (coho >79 mm in 1998 and 1999; coho >70 mm in 2001) in the total catch was generally similar for the mainstem RSTs and for weirs at the side-channels and Centre Creek (Table 4). Based on the data for 1999, the proportion of smolts captured in minnow traps (54%-78%) was substantially lower compared to smolts captured at weirs and RSTs (93%-98%; Table 4).

4.0 Discussion

4.1 Contribution of constructed side-channels to smolt production

Our assumption that juvenile coho less than 79 mm in fork length in 1998 and 1999, and less than 70 mm in 2001 were parr rather than smolts, was based on the observation that smaller fish generally did not exhibit physical characteristics typical of smolts. A portion of these smaller fish captured at the side-channel weirs and at RST(s) downstream, may have continued feeding in the mainstem or the estuary (Tschaplinski 1982), and entered the ocean as smolts later in the spring (Irvine and Ward 1989). Nevertheless, in 1998 and 1999, coho smaller than 79 mm represented less than 10% of the catch in the downstream traps, and those under 70 mm represented less than 1% of the catch in 2001. Thus, any underestimate of smolt numbers for the system would be relatively small. Furthermore, the inclusion of undersize coho would likely have little effect on the estimates of the smolt production component for the side-channels. This is because the proportion of undersize coho was generally similar for the side-channels and the mainstem/tributary area (Table 4).

In 1998, the mean weighted density of coho smolts (i.e, the sum of smolt numbers for the two channels given in Table 1 divided by the summed length of the channels) was 5.2 times higher for the two constructed side-channels than the mainstem/tributary area (4,212 versus 813 smolts·km^{-1}); in 1999 and 2001, it was 2.4 and 3.1 times higher, respectively (3,303 versus 1,385 smolts·km^{-1} in 1999, and 2,529 versus 810 smolts·km^{-1} in 2001). That is, in 1998, when the channels represented only 6% of the available habitat (by stream length), they supported 25% (? 6%) of the estimated total smolt population for the system (8,339 of 33,531 smolts; Table 1). Likewise, in 1999 and 2001, following expansion of the Weyerhaeuser site, the two channels represented 7% of the available habitat but supported 15% (? 2 %) and 19% (? 1%), respectively, of the estimated smolt populations (7,695 of 50,622 smolts in 1999, and 5,893 of 31,005 smolts in 2001; Table 1).

The high proportion of total smolt production accounted for by the constructed side-channels did not appear to be the result of underseeding of fry to other areas in the system. A coho smolt production model developed by Bradford et al. (2000) for Pacific coastal streams of similar latitude to the Englishman River predicted that, on average, the minimum escapement needed to fully seed a stream (i.e., achieve smolt carrying capacity) was 19 female spawners·km^{-1}. The Englishman River escapements corresponding to the 1998 and 1999 smolt years were qualitatively estimated based on shore counts, while escapement for the 2001 smolt year was estimated using diver surveys and AUC methodology. Assuming a spawner sex ratio of 45% females (Bradford et al. 2000), the estimated spawner densities for the years corresponding to the 1998, 1999 and 2001 smolt production years were 4, 3, and 43 females·km^{-1}, respectively. Comparing these values to the value of 19 females·km^{-1}, may suggest that the Englishman River was fully seeded in 2001, but not in 1998 and 1999 when brood escapements were low.

However, our results contradict this because the overall smolt production in 1999 was nearly double that in 2001, despite the apparently much lower spawner density for the 1999 smolt year. Moreover, during the three study years, the estimated coho smolt densities for the total Englishman River (including side-channels) ranged from 928 to 1,516 smolts·km^{-1} (Table 1). These values are in the same general range as the mean value of 1,476 coho smolts·km^{-1} reported for Pacific coastal streams of similar latitude which were thought to be fully seeded (Bradford et al. 1996).

It is likely that the 1998 and 1999 escapements estimates derived from shore counts were biased low. Adult coho are difficult to observe in streams; and non-stratified, shore-based, visual surveys of coho escapement are known to be highly inaccurate (Irvine et al. 1992). After participating in the underwater surveys for the 2001-2003 brood years, the field crew that conducted the shore-based surveys for the 1998 and 1999 brood years considered the earlier spawner counts to be underestimates of actual escapement (C. Young, Englishman River Hatchery Manager, pers. comm.).

Our study results may be conservative regarding the potential contribution of constructed side-channels to overall smolt production in a stream. During this study, smolt densities in the two side-channels averaged 0.34 smolts·m^{-2} (range: 0.22 - 0.63 smolts·m^{-2}; Table 1). By comparison, a higher mean density of coho smolts was observed for a large data set of constructed side-channels in B.C. and the Pacific Northwest (0.69 smolts·m^{-2}) (Koning and Keeley 1997). Thus, the numbers of smolts outmigrating from the Englishman River side-channels in this study may underestimate the potential carrying capacity of this type of habitat.

Although no censuses of spawner abundance at the side-channel sites were conducted, below-average smolt production in the Englishman River side-channels may have been influenced by low adult returns to these sites despite their close proximity to known major coho spawning areas in the mainstem. Other studies suggest that underescapement of coho spawners to constructed side-channels may be fairly common (Peterson 1985; Decker 1999; Decker and Lewis 1999). To increase the likelihood of attracting adult spawners or juveniles searching for overwintering habitat, the side-channel outlets at the confluence with the mainstem, could be enhanced by increasing structural complexity in the form of artificial log jams or debris structures.

Though the data are too sparse to draw strong conclusions, our study suggests that the Englishman side-channels may support a greater proportion of the total smolt population in the system during years when the overall juvenile abundance is relatively low. Figure 8a shows that the mean weighted density of coho smolts in the channels (i.e, the sum of smolt numbers for the two channels in each year divided by the summed area of the channels, see Table 1) was quite similar for the three study years (0.38, 0.32, 0.25 smolts/m^2 for 1998, 1999 and 2001, respectively), despite a much higher total smolt abundance in the system in 1999 compared to the other two years. As a result, the side-channels contributed more to the total smolt production in the system during the two years when the total smolt abundance was low (Figure 8b). This observation further supports our findings that artificial side-channels provide preferred winter habitat in the Englishman River. In a study of coho populations in two B.C. interior streams, Bratty (1999) also noted proportionally higher utilization of off-channel compared to mainstem habitat during years when the overall juvenile abundance was relatively low. Other researchers have made similar observations (Tschaplinski and Hartman 1983; Sheng et al. 1990; Decker 1998).

The relatively high use of artificial side-channels by overwintering juvenile coho in the Englishman River is comparable to the relative use of natural and/or artificial off-channel areas by coho in other streams. Lestelle et al. (1993) found that as many as 30% of coho in the Queets River (WA) reared in natural or man-made off-channel ponds during part of the year. Brown and Hartman (1988) found that an average of 19% of coho in Carnation Creek, B.C. overwintered in natural off-channel habitat. Decker and Lewis (1999), during their two-year study, found that nearly half of the smolts in the Coquitlam River, B.C., overwintered in six constructed off-channel ponds which represented only about 14% of the available habitat. Likewise, Everest et al. (1986) reported that, three years after construction, an artificial off-channel pond in Fish Creek, (OR) which represented only 1% of the total rearing area, contributed 50% to the total coho smolt output.

Other studies have shown that coho smolt carrying capacity is limited by the availability of suitable winter habitat (Lestelle et al. 1993; Hartman et al. 1996; Solazzi et al. 2000), and that overwinter survival of coho rearing in off-channel habitat is relatively high (Peterson 1982; Brown 1985; Swales and Levings 1987). In this study, we did not assess the relative survival of overwintering coho in the side-channel and mainstem/tributary areas. However, assuming that winter habitat is a limiting factor for Englishman River coho for all but very low levels of adult escapement (Hartman et al. 1996), and given the apparent preference of juveniles for artificial side-channels, based on relative smolt densities (Table 1), it is likely that side-channel construction has increased the productive capacity of this system.

Studies of naturally occurring off-channel areas showed that these are used primarily as winter habitat by juveniles emigrating from the mainstem during the fall (Cederholm and Scarlett 1982; Peterson 1982; Brown and Hartman 1988). However, studies of artificial side-channels found that most of these juveniles were year-round residents with recruitment dependent mainly on spawning within restored sites (Peterson 1985; Sheng et al. 1990; Decker 1999; Decker and Lewis 1999). Therefore, the relatively high smolt densities observed in the side-channels in this study may indicate that this type of habitat is used for winter rearing, as well as adult spawning and summer rearing of resulting fry.

4.2 Reliability of mark-recapture estimates

For the 1999 and 2001 data, the pooled Petersen estimator provided a fairly precise estimate (95% CI = 12% and 4%, respectively) of total coho smolt abundance in the Englishman River system. By comparison, the precision of the 1998 Darroch estimate was lower (CI = 32%), despite the use of a maximum likelihood estimator and stratification of catch data by release and recovery period. This lower precision of the 1998 estimate was attributed to lower capture efficiency, and hence fewer fish being recovered (capture efficiency ranged from 0.8%-5.2% in 1998 compared to 3.4%-7.8% in 1999 and 10.2%-19.6% in 2001; Table 2). Similar to our study, Carlson et al. (1998) found that for estimating numbers of downstream migrating salmon smolts, capture efficiencies at downstream traps of 10%-20% were necessary to provide confidence intervals of ? 10% or less.

Poor capture efficiency has been cited as a cause of imprecise estimates of smolt numbers in other studies (Dempson and Stansbury 1991; Cope 1998; Miyakoshi et al. 1998). In this study, the use of full-span weirs to enumerate smolts from the side-channels was an efficient means of obtaining a large marked population necessary to estimate smolt numbers from the mainstem and tributaries. However, our experience suggests that proper location and operation of RSTs and other partial-span traps, is also an important consideration. For example in 1999, smolt catch for RST 1, despite its shorter period of operation, was 11 times greater than that for RST 2 (1,552 versus 139). This was the result of a larger screen mesh being used for RST 1 compared to RST 2 (13 mm versus 3 mm). Also, the relatively high capture efficiency for both RSTs in 2001 (Table 2) was the result a larger mesh size (16 mm) being used. It is therefore recommended that to improve the capture efficiency of RSTs, a 13 mm or larger mesh screen should be used.

Stratified mark-recapture estimators may not necessarily provide more reliable population estimates than non-stratified ones, in cases where assumptions of population closure, constant capture efficiency and constant proportions of marked to unmarked fish over time are not met. During all years of the study, the assumption of population closure was likely met, as most fish moved through the release and recovery sites during the sampling period (Figures 4-6). However, the assumption of constant RST capture efficiency over time was not met. During 1998, when smolts were differentially marked according to release date, capture efficiency of the RST varied considerably during the course of the smolt migration (Table 3a), but did not appear to be related to temperature or discharge. Also, the assumption of constant proportions of marked to unmarked fish over time was not met in 1998 or 1999. During these years, the majority of coho from the mainstem and tributaries moved through the recovery site earlier compared to side-channel coho (Figure 7), resulting in a higher proportion of marked side-channel smolts during the latter half of smolt run (Table 3).

Failure to meet the above two assumptions did not appear to seriously bias the 1998 PPE estimates which were similar to those obtained using the Darroch estimator with temporally stratified data (Table 1). In other studies, PPE estimates of migrating fish populations were also robust to violations of these assumptions (e.g., Atlantic salmon (*Salmo salar*) smolts, Dempson and Stansbury 1991; masu salmon (*Oncorhynchus masou*) smolts, Miyakoshi et al. 1998; pink salmon adults, Schwarz and Taylor 1998.) However, there are exceptions to this (e.g., Irvine et al. 1995; Melville and McCubbing 2000).

In the above Melville and McCubbing study, PPE estimates of smolt numbers in the Cheakamus River, B.C. were likely biased as a result of reduced RST capture efficiency due to high spring discharge; the high flows occurred at the end of the study period (late May and June) which coincided with the peak of smolt migration. As a result, the PPE estimates were biased low because the relatively few earlier migrating smolts were more likely to be captured in the RSTs, and hence were over-represented in the recovery data (Carlson et al. 1998). By comparison, for Englishman River in 1998, capture efficiency remained relatively high and constant during the period when an estimated 88% of the smolts outmigrated (based on catch data for the full-span weirs in the side-channels). We therefore recommend that for these types of studies, particularly in streams with pronounced spring freshets, fish marking should be stratified by release period; this can be done with little extra cost or effort when using Pan-jet marking techniques. Without stratified marking, there is no means of determining whether failure to meet the assumption of constant capture efficiency over time has biased the population estimates.

We could not test directly whether the RST capture efficiency differed for marked fish from side-channels compared to unmarked fish from the mainstem/tributary area. However, the assumption of equal catchability is crucial because stratified mark-recapture estimators cannot be used to identify or correct for this anomaly (Schwarz and Dempson 1994). In our study, smolts captured in RST 1 (1998) or in minnow traps (1999), and released into the mainstem upstream, were more likely to be recaptured in the RSTs downstream than smolts released from the side-channels (Table 2). This apparent higher capture efficiency for mainstem/tributary smolts may have been the result of random error; in both years, recoveries of mainstem/tributary fish were few (9 and 10 smolts in 1998 and 1999, respectively).

Compared to 1998 and 1999, the numbers of recaptures in 2001 for the various mark groups at both RSTs were much higher, ranging from 335 to 948 smolts (Table 2). In 2001, unequal capture efficiency among mark groups at RST 1 was observed only for the marked Centre Creek smolts – 14.8% compared to 18.5% and 19.6% for marked side-channel and mainstem/tributary smolts, respectively. As a result, RST 1 recovery data for Centre Creek smolts produced a higher estimate of total smolt abundance (36,783 smolts) compared to estimates based on side-channel data (29,436 smolts) and mainstem/tributary data (27,737 smolts; Table 1).

The lower RST 1 capture efficiency for Centre Creek smolts in 2001 did not appear to be related to migration timing differences as all smolt groups showed a similar timing that year (Figure 7). Rather, the relatively smaller size of Centre Creek smolts compared to smolts from the side-channels and the mainstem/tributary area may have led to their lower capture efficiency (Table 4). However, this latter explanation is unlikely because a lower capture efficiency is generally associated with larger-sized fish, given their greater swimming ability (Ricker 1975). A more plausible explanation would be that a portion of the smaller coho captured at the Centre Creek weir were parr migrating to rear in the mainstem rather than seaward migrating smolts (Irvine and Ward 1989).

To compare side-channel and mainstem/tributary smolt production in 2001, we chose the smolt abundance estimate for the mainstem/tributary area that was based on pooled recovery data from RST 1 for all three groups of marked smolts (side-channels, Centre Creek, mainstem/tributary). This estimate (31,005 smolts) was roughly median to the range of smolt abundance estimates computed using recovery data for the various mark groups at each RST (range: 27,737 - 37,531 smolts; Table 1). We chose to use this estimate because it was likely more reliable than those generated using data from RST 2. At RST 1, the proportion of marked to unmarked smolts captured was fairly constant during May 5 - June 15 when 95% of the smolts migrated. Weekly marked proportions at RST 2 were considerably more variable (Table 3 c,d). Moreover, as mentioned above, capture efficiency at RST 1 during 2001 was similar for marked smolts from the side-channels and the mainstem/tributary area and only marginally lower for marked smolts from Centre Creek (Table 2). This suggests, indirectly, that capture efficiency at RST 1 for marked (predominately side-channel) and unmarked (predominately mainstem/tributary) smolts was reasonably similar as well.

It was unclear why the smolt abundance estimates generated using RST 2 data were higher than those generated using data from RST 1 (Table 1). For the RST 2 data, it was not possible to compare capture efficiency for smolts from the side-channels and Centre Creek to those from the mainstem/tributary area because no marked mainstem/tributary smolts were released upstream of RST 2.

5.0 CONCLUSIONS

Artificial side-channels in the Englishman River were readily colonized by large numbers of wild coho salmon, and channel outmigrants contributed substantially to overall smolt production in the system. However, in order to state unequivocally that side-channel development has increased the overall smolt production in the system, a long-term monitoring program would have to be conducted before and after enhancement. This was not possible for the Englishman River. Nevertheless, our study indicates that the construction of two side-channels in the Englishman River has affected the distribution of coho production. If it is assumed that coho smolt production in the Englishman River is limited by overwintering habitat, then it is reasonable to suggest that overall coho productive capacity of the system has been increased as a result of side-channel construction.

The mark-recapture sampling design used here appears to be a practical way to estimate the abundance of migrating smolts in streams too large too accommodate full-span downstream weirs.

6.0 SUMMARY

1. In 1992 and 1989/98, two side-channels (Timber West and Weyerhaeuser) were constructed in the Englishman River to increase off-channel rearing habitat for juvenile coho salmon.

2. The primary objective of the study was to assess the contribution of these side-channels to overall coho smolt production in the Englishman River system. The secondary objective was to examine the utility and problems associated with the use of a stratified mark-recapture sampling design to estimate numbers of migrating smolts.

3. Numbers of smolts outmigrating from the two side-channels were based on weir counts, while numbers of smolts estimated for the entire system were based on a mark-recapture sampling design, with rotary screw traps (RSTs) used to recapture the mainstem smolts.

4. For 1998, 1999 and 2001, coho smolts outmigrating from the channels totalled 8,339, 7,695 and 5,893, respectively, while smolt numbers for the entire system were estimated at 33,531 (? 10,605), 50,622 (? 5,873) and 31,005 (? 1,127), respectively.

5. It was evident that the artificial side-channels represented preferred overwintering habitat in the Englishman River system. While the channels accounted for less than 8% of the total stream area (by channel length), in 1998, 1999 and 2001, coho smolt outmigrants from these sites represented 25% (? 6%), 15% (? 2%) and 19% (? 1%), respectively, of the estimated total smolt production in the system. For the respective years, the mean density of outmigrating coho smolts was 5.2, 2.4 and 3.1 times greater for the side-channel area compared to the mainstem/tributary area.

6. The use of RSTs and mark-recapture methodology appears to be a practical way to estimate the abundance of migrating smolts in larger streams, such as the Englishman River where the installation of full-span downstream weirs in the mainstem is not possible.

7. In 2001, the use of larger diameter screening on the RSTs compared to the two previous study years, led to increased capture efficiency (10%-20% versus 1%-8%). This resulted in greater precision for the 2001 smolt population estimate (95% CI: ? 4%) compared to the 1998 and 1999 smolt estimates (95% CI: ? 32% and ? 12%, respectively).

8. In all but one case during 2001, capture efficiency was similar among mark groups at each RST. This provided indirect evidence that the assumption of equal catchability for marked and unmarked smolts was reasonably met. Accordingly, for the 2001 data, the discrepancy among the population estimates computed for the individual mark groups was comparatively low (29,436 - 37,531 smolts). By contrast, for 1998 and 1999, RST capture efficiency differed for marked side-channel and marked mainstem/tributary smolts, suggesting, indirectly, that the assumption of equal catchability was not met. This may have led to a high discrepancy among individual population estimates during both years (1998: 10,172 - 64,685 smolts; 1999: 21,110 - 50,622 smolts). However, discrepancies among population estimates in 1998 and 1999 were more likely the result of random error due to low recoveries for marked mainstem/tributary smolts. In future assessments, the potential bias resulting from unequal catchability for marked side-channel and unmarked mainstem/tributary smolts would be best addressed by continuing to mark and recapture large numbers of smolts from both areas as was done in 2001.

7.0 REFERENCES

Anon. 1987. Fish Habitat Inventory and Information Program. Stream Summary Catalogue Subdistrict #14. Canada Department of Fisheries and Oceans, South Coast Division.

Arnason, A.N., C.W. Kirby, C.J. Swartz, 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.

Boom, A. and G. Bryden. 1993. Englishman River water allocation plan. Ministry of Environment Lands and Parks, Regional Water Management, Nanaimo, B.C. Unpublished report.

Bradford, M. J., G. C. Taylor, and J. A. Allan. 1996. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Tran. Amer. Fish. Soc. 126:49-64.

Bradford, M. J., R. A. Myers, and J. R. Irvine. 2000. Reference points for coho salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Can. J. Fish. Aquat. Sci. 57: 677-686.

Bratty, J.M. 1999. The winter ecology of juvenile coho salmon in interior British Columbia streams. M.Sc. thesis. University of British Columbia, Vancouver B.C.

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.

Brown, T.G. 1985. The role of abandoned stream channels as over-wintering habitat for juvenile salmonids. Master's thesis. Univ. of British Columbia, Vancouver, Canada.

Brown, T.G., and G.F. Hartman. 1988. Contributions of seasonally flooded lands and minor tributaries to the production of coho salmon (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. Tran. Amer. Fish. Soc. 177: 546-551.

Carlson, S. R., L. G. Coggins, and C. O. Swanton. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fisheries Research Bulletin 5:88-102.

Cederholm, C.J., and W.J. Scarlett. 1982. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. *In* E.L. Brannon and E. Salo, (eds.). Proceedings of the salmon and trout migratory symposium. Univ. of Washington, School of Fisheries, Seattle: pp. 98-110.

Conlin, K. and B.D. Tutty. 1979. Juvenile field trapping manual. Fish. and Mar. Serv. Man. Rep. #1530.

Cope, R.S. 1998. Alouette River salmonid smolt migration enumeration. Unpublished report prepared for B.C. Hydro Power Facilities, Burnaby, B.C. (Nov. 1998).

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts form land-use activity. Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 267-282.

Darroch, J.N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48: 241-260.

Decker, S. 1998. Influence of off-channel habitat restoration and other enhancement on the abundance and distribution of salmonids in the Coquitlam River. Unpublished report prepared for B.C. Hydro Power Facilities, Burnaby, B.C. 35 p.

Decker, A.S. 1999. Effects of primary production and other factors on the size and abundance of juvenile coho salmon in constructed off-channel habitat. M.Sc. thesis. University of British Columbia, Vancouver B.C.

Decker, S., and G. Lewis. 1999. Response of salmonids to off-channel habitat restoration and increased minimum flows in the Coquitlam River. Unpublished report prepared for B.C. Hydro Power Facilities, Burnaby, B.C., December 1999. 49 p.

Decker, S., and G. Lewis. 2000. Fish Response to Increased Minimum Flows and Habitat Restoration in the Coquitlam River: a 5 Year Review. Unpublished report prepared for B.C. Hydro Power Facilities, Burnaby, B.C., December 2000. 40 p.

Dempson, J.B., and D.E. Stansbury. 1991. Using partial counting fences and a two-sample stratified design for mark-recapture estimation of an Atlantic salmon smolt population. N. Am. J. Fish. Mange. 11: 27-37.

Everest, F.H., G.H. Reeves, J.R. Sedell, J. Wolfe, D. Hohler, and D.A. Heller. 1986. Abundance, behavior, and habitat utilization by coho salmon and steelhead in Fish Creek, Oregon, as influenced by habitat enhancement. 1985 Annual Report, Bonneville Power Administration, Division of Fish and Wildlife. Project 84-11, Portland, OR.

Frissell, C.A., and R.K. Nawa. 1992. Incidence and causes of physical failure of constructed habitat structures in streams in western Oregon and Washington. N. Amer. J. Fish. Mange.12: 182-197.

Hamilton, R.E. and G. T. Kosakoski. 1982. Water requirements for the fisheries resource of the Englishman River, Vancouver Island, B.C. Can. Man. Rep. Fish. Aquat. Sci. 1676.

Hartman, G.F., J.C. Scrivener, and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high energy coastal stream in British Columbia, and their implication for restoring fish habitat. Can. J. Fish. Aquat. Sci. 53 (Suppl.1): 237-251.

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. Department of Fisheries and Oceans. Unpublished internal report.

Irvine, J. R., and B. R. Ward. 1989. Patterns of timing and size of wild coho salmon smolts migrating from the Keogh River watershed on northern Vancouver Island. Can. J. Fish. Aquat. Sci. 46: 1086-1094.

Irvine, J. R., R. C. Bocking, K. K. English, and M. Labelle. 1992. Estimating coho salmon spawning escapements by conducting visual surveys in areas selected using stratified random and stratified index sampling designs. Can. J. Fish. Aquat. Sci. 49: 1972-1981.

Irvine, J.R., Y Miyakoshi, H. Hayano, M. Fujiwara, K. Sugiwaka, M. Miyamoto, and M. Nagata. 1995. Assessment of hatchery origin and wild masu salmon (*Oncorhynchus masou*) smolts in the Masuhoro River, 1995.

Keeley, E.R., and C.J. Walters. 1996. The British Columbia Watershed Restoration Program: summary of the experimental design, monitoring and restoration techniques workshop. Province of British Columbia, Ministry of Environment, Lands and Parks and Ministry of Forests. Watershed Restoration Project Report No. 4:34 p.

King, D., and R. Young. 1986. An evaluation of four groundwater-fed side channels of the east of fork of the Satsop River - spring 1985 outmigrants. State of Washington , Department of Fisheries. Technical Report 90: 73 p.

Koning, C.W., and E.R. Keeley. 1997. Salmonid biostandards for estimating production benefits of fish habitat rehabilitation techniques. *In* P.A. Slaney and D. Zaldokas. [eds.] Fish habitat rehabilitation procedures. Watershed Restoration Technical Circular No. 9.

Lestelle, L.C., G.R. Blair, and S.A. Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. *In*: Proceedings of the 1992 coho workshop. Nanaimo, BC: pp. 104-119.

Lister, D.B., R.J. Finnigan. 1997. Rehabilitating off-channel habitat. *In* P.A. Slaney and D. Zaldokas. [eds.] Fish habitat rehabilitation procedures. Watershed Restoration Technical Circular No. 9.

Melville, C., and D. McCubbing. 2000. Assessment of the 2000 juvenile salmon migration from the Cheakamus River, using rotary screw traps. Unpublished report prepared for B.C. Hydro and Power Authority, Vancouver, B.C. 40 p.

Miyakoshi, Y., H. Hayano, M. Fujiwara, K. Sugiwaka, and J.R. Irvine. 1998. Assessment of hatchery origin and wild masu salmon (*Oncorhynchus masou*) smolts in the Masuhoro River, 1996. Scientific Reports of the Hokkaido Fish Hatchery 52: 1-10.

Nickelson, T.E., M.F. Solazzi, S.L. Johnson, and J.D. Rodgers. 1993. An approach to determining stream carrying capacity and limiting habitat for coho salmon. *In:* Proceedings of the 1992 coho workshop. Nanaimo, B.C. pp. 251-260.

Nickelson, T.E., J.D. Rodgers, S.L. Johnson, and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49: 783-789.

Peterson, N.P. 1982. Population characteristics of juvenile salmon (Oncorhynchus kisutch) over-wintering in riverine ponds. Can. J. Fish. Aquat. Sci. 39: 1303-1307.

Peterson, N. P. 1985. Riverine pond enhancement project: October 1982 - December 1983. Wash. Dep. Fish. and Wash. Dep. Nat. Resour. Prog. Rep. 233, Olympia, WA. 48 p.

Plante, N. 1990. Estimation de la taillee d'une population animale a l'aide d'un modele de capture-recapture avec stratification. M.Sc. thesis, Universite Laval, Quebec.

Quinn, T.P., and Peterson, N.P. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Can. J. Fish. Aquat. Sci. 53: 1555-1564.

Reeves, G.H., J.D. Hall, T.D. Roelofs, T.L. Hickman, and C.O. Baker. 1991. Rehabilitating and modifying stream habitats. *In* Meehan, W.R. [ed.] Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, MD.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Department of the Environment, Fisheries and Marine Service, Ottawa, Canada.

Riley, S.C., and K.D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Can. J. Fish. Aquat. Sci. 52: 34-53.

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

Schwarz, C.J., and C.G. Taylor. 1998. Use of the stratified-Petersen estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Can. J. Fish. Aquat. Sci. 55:281-296.

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

Sharma, R., and R. Hillborn. 2001. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. Can. J. Fish. Aquat. Sci. 58: 1453-1463.

Simpson, K., R. Semple, D. Dobson, J. Irvine, S. Lehmann, and S. Baillie. 2000. Status in 1999 of coho stocks adjacent to the Strait of Georgia. Canadian Stock Assessment Secretariat. Research Document 2000/158.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry, principles and practices of statistics in biological research, 2nd edition. W.H. Freeman Company, New York.

Solazzi, M. F., T. E. Nickelson, S. L. Johnson, and J. D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal oregon streams. Can. J. Fish. Aquat. Sci. 57: 906-914.

Swales, S., and C.D. Levings. 1987. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Can. J. Fish. Aquat. Sci. 46: 232-242.

Thedinga, J.F. and four other authors. 1994. Determination of salmonid smolt yield with rotary-screw traps in the Situk River, Alaska, to predict the effect of glacial flooding. N. Amer. J. Fish. Manage. 14: 837-851.

Tschaplinski, P. J. 1982. Aspects of the population biology of estuary-reared and stream-reared juvenile coho salmon in Carnation Creek: a summary of current research. Pages 289-307 in G. F. Hartman, ed. Carnation Creek Workshop: a ten year review. Department of Fisheries and Oceans, Nanaimo, B. C.

Tschaplinski, P.J., and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (Oncorhynchus kisutch) before and after logging in Carnation Creek, British Columbia, and some implications for over-winter survival. Can. J. Aquat. Sci. 400: 452-461.

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Table 1. Summary of estimated numbers and densities of coho smolts in 1998, 1999 and 2001 for Weyerhaeuser (W) and Timber West (TW) side-channels, Centre Creek (CC, 2001 only), the mainstem/tributary area (MT), and the total Englishman River system (Total). Smolt numbers for channels were estimated using counts at full-span downstream weirs, smolt numbers for the mainstem/tributary area were estimated using either the Darroch estimator (rotary screw trap, and data stratified by release and recovery period, 1998 only) or the Petersen pooled estimator (PPE) (RST and non-stratified data, 1998, 1999, 2001).

Site	Length (km)	Area (m^2)	Estimation method	Release group	Recovery site	N smolts	CI ???	CI ?? ?	Smolt density /km	Smolt density $/m^2$	% of smolt run
1998											
W	0.6	4,000	Count (incl. below weir)			817	-	-	1,362	0.2	2.4%
TW	1.4	17,709	Count (incl. below weir)			7,522	-	-	5,451	0.4	22.4%
MT	31.0		Darroch	All[1]	RST	25,192	10,605	42%	813		75.1%
Total	33.0		Darroch	All	RST	33,531	10,605	32%	1,017		100%
Total	33.0		PPE	All	RST	34,578	5,143	15%			100%
Total	33.0		PPE	W	RST	64,685 [2]	44,536	69%			100%
Total	33.0		PPE	TW	RST	32,620	5,001	15%			100%
Total	33.0		PPE	MT	RST	10,172 [2]	5,987	59%			100%
1999											
W	1.0	6,000	Count (incl. below weir)			3,777	-	-	3,976	0.6	7.5%
TW	1.4	17,709	Count (incl. below weir)			3,918	-	-	2,839	0.2	7.7%
MT	31.0		PPE	All	RST 1&2	42,927	5,873	14%	1,385		84.8%
Total	33.4		PPE	All	RST 1&2	50,622	5,873	12%	1,516		100%
Total	33.4		PPE	W	RST 1&2	48,657	8,230	17%			100%
Total	33.4		PPE	TW	RST 1&2	52,310	8,594	16%			100%
Total	33.4		PPE	MT	RST 1&2	21,110 [2]	11,402	54%			100%
2001											
W	1.0	6,000	Count (incl. below weir)			2,061	-	-	2,170	0.3	6.6%
TW	1.4	17,709	Count (incl. below weir)			3,832	-	-	2,777	0.2	12.4%
CC	5.2	-	Count (incl. below weir)			3,828	-	-	736		
MT[3]	31.0	-	PPE	All	RST 1	25,112	1,127	4%	810		81.0%
Total	33.4	-	PPE	All	RST 1	31,005	1,127	4%	928		100%
Total	33.4		PPE	Channels	RST 1	29,436	1,690	6%	881		100%
Total	33.4		PPE	CC	RST 1	36,783	3,105	8%	1,101		100%
Total	33.4		PPE	MT	RST 1	27,737	2,536	9%	830		100%
Total	33.4		PPE	Channels	RST 2	36,485	2,821	8%	1,092		100%
Total	33.4		PPE	CC	RST 2	37,531	3,802	10%	1,124		100%

[1] For 1998 and 1999 data, *All* refers to marked smolts from the Weyerhaeuser and Timber West side-channels. For the 2001 data, *All* refers to channel mark groups, as well as marked smolts from Centre Creek (see Section 2.2.1).

[2] Estimate based on a low number of recaptures (see Table 2).

[3] Includes smolt numbers for Centre Creek.

Table 2. Mark-recapture statistics for coho smolts at all release and recovery sites in the Englishman River during 1998, 1999 and 2001.

Release Site	Marked fish released	Marked fish recovered	Unmarked fish recovered	Capture efficiency (CE)[1]
1998				
Weyerhaeuser	778	6		0.8%
Timber West	7,014	124		1.8%
Sub-Total Channels	7,792	130		
Mainstem	174	9		5.2%
Total	7,966	139	415	
1999 (RST 1& RST 2)				
Weyerhaeuser	3,209	118		3.7%
Timber West	3,653	125		3.4%
Sub-Total Channels	6,862	243		
Mainstem	128	10		7.8%
Total	6,990	253	1,438	
2001 (RST 1)				
Weyerhaeuser	1,569			
Timber West	3,559			
Sub-Total Channels	5,128	948		18.5%
Centre Creek	3,288	486		14.8%
Mainstem	2,143	420		19.6%
Total	10,559	1,854	3,281	
2001 (RST 2)				
Weyerhaeuser	1,569			
Timber West	3,559			
Sub-Total Channels	5,128	538		10.5%
Centre Creek	3,288	335		10.2%
Total	8,416	873	2,500	

[1] Capture efficiency is defined as the percentage of coho marked at a release site that were recovered downstream in a rotary screw trap(s).

Table 3. Numbers of coho smolts marked and released, numbers of marked and unmarked smolts recovered, percentages of marked smolts recovered (capture efficiency), and the proportion of marked smolt for each recovery period for the Englishman River during 1998, 1999 and 2001. In Table 3a, marked smolts released refers to the number of smolts marked and released from the combined Weyerhaeuser and Timber West side-channels.

A. 1998			Recovery stratum							Capture
		Marked	1	2	3	4	5	6	7	efficiency
Release	Release	smolts	15-Apr	27-Apr	4-May	11-May	20-May	25-May	1-Jun	per release
stratum	period	released	26-Apr	3-May	10-May	19-May	24-May	31-May	10-Jun	stratum
1	15 Apr - 23 Apr	39	1	0	0	0	0	0	0	2.6%
2	27 Apr - 3 May	1,065	0	9	9	0	0	0	0	1.7%
3	4 May - 10 May	1,914	0	0	26	4	0	0	0	1.6%
4	11 May - 19 May	2,930	0	0	0	31	5	2	0	1.3%
5	20 May - 24 May	848	0	0	0	0	11	5	0	1.9%
6	25 May - 31 May	824	0	0	0	0	0	20	7	3.3%
7	1 Jun - 10 Jun	172	0	0	0	0	0	0	0	0.0%
Unmarked smolts			18	169	91	55	19	50	13	
Total recovered			19	178	126	90	35	77	20	
Proportion of marked smolts			5%	5%	28%	39%	46%	35%	35%	
B. 1999	Release		30-Apr	15-May	20-May	25-May	30-May	4-Jun	9-Jun	
RST 1&2	site		14-May	19-May	24-May	29-May	3-Jun	8-Jun	13-Jun	
1	Englishman River	128	0	2	7	0	1	0	0	7.8%
2	Weyerhaeuser	3,209	0	16	19	11	43	20	9	3.7%
3	Timber West	3,653	0	17	23	7	45	19	14	3.4%
Unmarked smolts			13	455	354	60	407	93	56	
Total recovered			13	490	403	78	496	132	79	
Proportion of marked smolts			0%	7%	12%	23%	18%	30%	29%	
C. 2001	Release		18-Apr	27-Apr	5-May	13-May	21-May	29-May	6-Jun	
RST 1	site		26-Apr	4-May	12-May	20-May	28-May	5-Jun	13-Jun	
1	Englishman River	2,143	0	16	40	91	120	125	28	19.6%
2	Side-channels	5,128	0	6	56	150	205	373	158	18.5%
3	Centre Creek	3,288	0	8	19	136	113	147	63	14.8%
Unmarked smolts			120	107	258	633	716	1,037	410	
Total recovered			120	137	373	1,010	1,154	1,682	659	
Proportion of marked smolts			0%	22%	31%	37%	38%	38%	38%	
D. 2001	Release		24-Apr	27-Apr	5-May	13-May	21-May	29-May	6-Jun	
RST 2	site		26-Apr	4-May	12-May	20-May	28-May	5-Jun	13-Jun	
1	Side-channels	5,128	0	9	54	110	181	119	65	10.5%
2	Centre Creek	3,288	0	17	30	119	119	35	15	10.2%
Unmarked smolts			117	347	305	551	690	366	124	
Total recovered			117	373	389	780	990	520	204	
Proportion of marked smolts			0%	7%	22%	29%	30%	30%	39%	

Table 4. Mean fork lengths, sample sizes (N), and standard errors (SE), and percentages of total catch for coho larger than 79 mm at all sites in the Englishman River during 1998, 1999 and 2001.

Year	Capture site	Mark group	Mean length[1]	*N*	SE	Percent of catch of smolt size[1]
1998	Weyerhauser weir	All smolts	98	775	0.3	99%
	Timber West weir	All smolts	95	6,322	0.1	93%
	RST	Marked Timber West smolts	97	108	1.0	100%
	RST	Unmarked smolts	96	114	0.7	98%
1999	Weyerhauser weir	All smolts	94	1,828	0.2	98%
	Weyerhauser minnow traps	All smolts	89	342	0.4	78% [2]
	Timber West weir	All smolts	96	2,074	0.2	93%
	RST 1 & 2	Marked Weyerhauser smolts	92	88	0.8	
	RST 1 & 2	Marked Timber West smolts	95	91	0.9	
	RST 1 & 2	Unmarked smolts	93	991	0.3	93%
	Mainstem minnow traps	All smolts	87	849	0.5	54% [2]
2001	Channel weirs	All channel smolts	87	731	0.3	99%
	Centre Creek weir	All Centre Creek smolts	82	853	0.7	> 99%
	RST 1	Marked channel smolts	93	245	0.3	
	RST 1	Marked Centre Cr. smolts	89	182	0.2	
	RST 1	Marked mainstem/trib smolts	92	194	0.2	
	RST 1	Unmarked smolts	91	409	0.5	> 99%
	RST 2	Marked channel smolts	90	290	0.2	
	RST 2	Marked Centre Cr. smolts	88	346	0.9	
	RST 2	Unmarked smolts	87	628	0.6	> 99%

[1] *Smolts* refers to coho > 79 mm fork length in 1998 and 1999, and to coho > 70 mm in 2001.
[2] Minnow-trapped fish.

Figure 1. Map of the Englishman River showing tributaries and artificial side-channels – Timber West (TW) and Weyerhaeuser (W). Inset map shows the location of the watershed on the east coast of Vancouver Island.

Figure 2. Map of the lower Englishman River and side-channels showing capture, release and recovery sites for juvenile coho in 1998, 1999 and 2001 (RST - rotary screw trap).

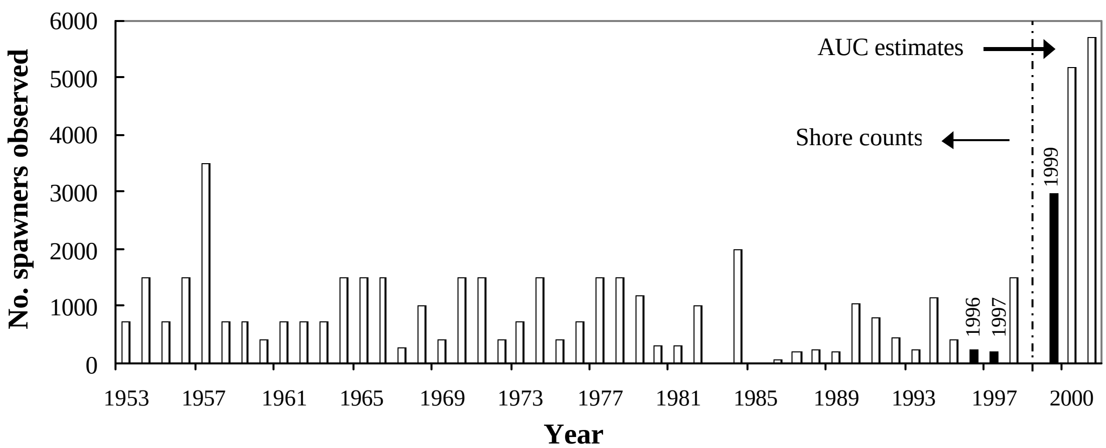


Figure 3. Estimated coho escapements to the Englishman River, based on numbers of adults observed during shore surveys and area-under-the-curve (AUC) methodology (SEDS, DFO, unpublished data). The solid labeled columns indicate brood year escapements associated with smolt abundance during the 1998, 1999 and 2001 study years.

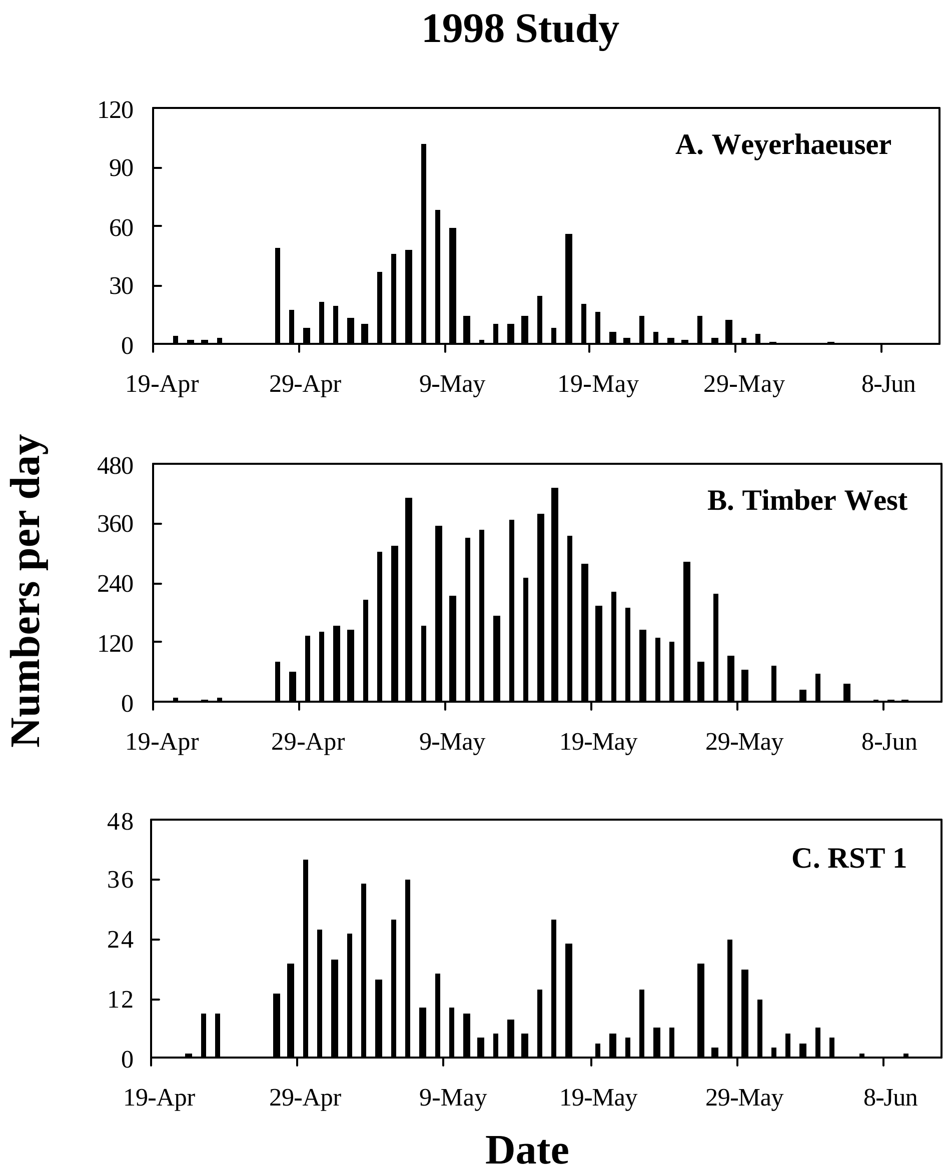


Figure 4. Daily catches of coho smolts at the Weyerhaeuser and Timber West side-channel sites and at the rotary screw trap (RST 1) in the Englishman River during 1998.

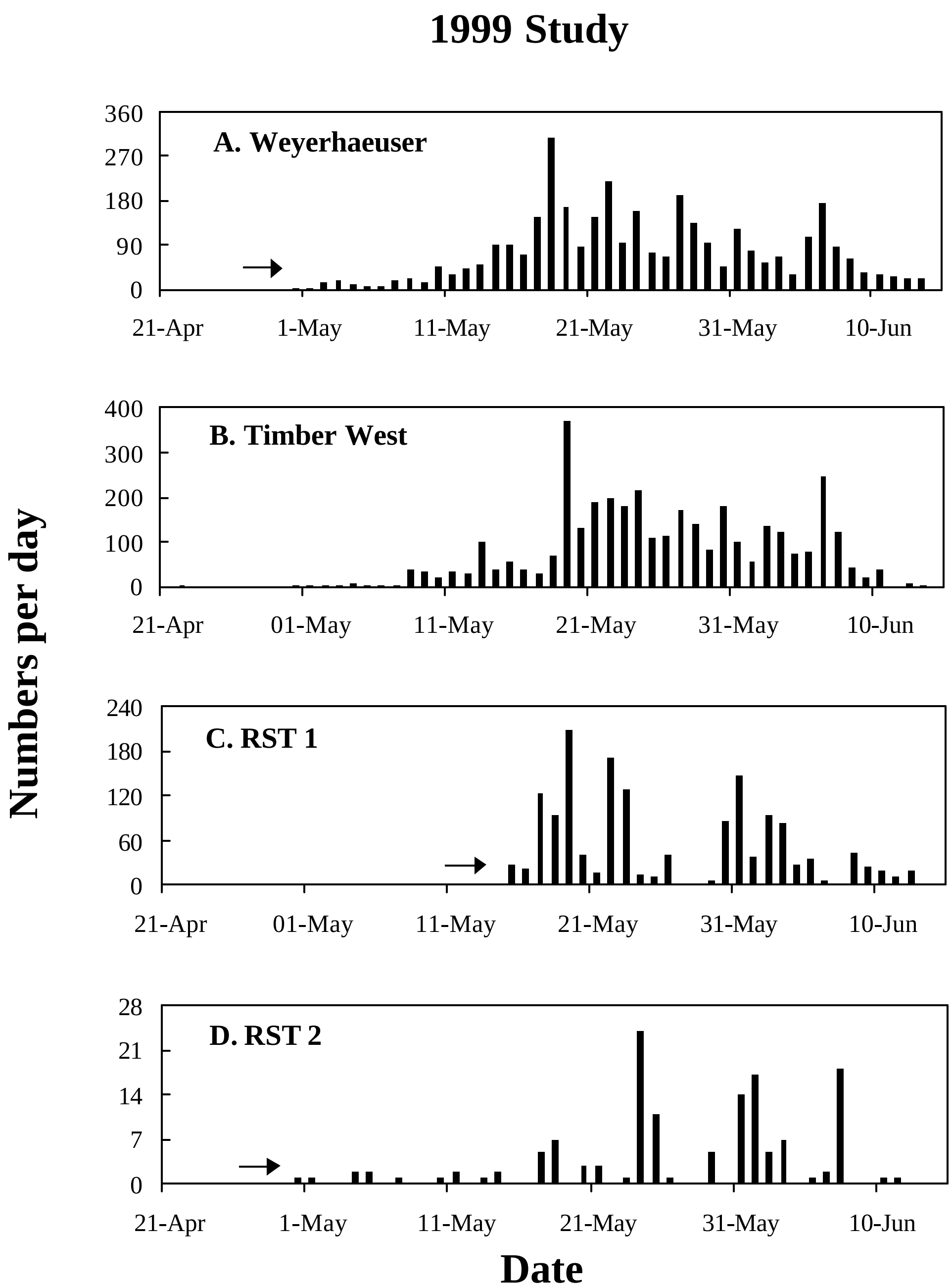


Figure 5. Daily catches of coho smolts at the Weyerhaeuser and Timber West side-channel sites and at two rotary screw traps (RST 1 and RST 2) in the Englishman River during 1999 (where present, arrows indicate beginning or end dates for downstream trapping).

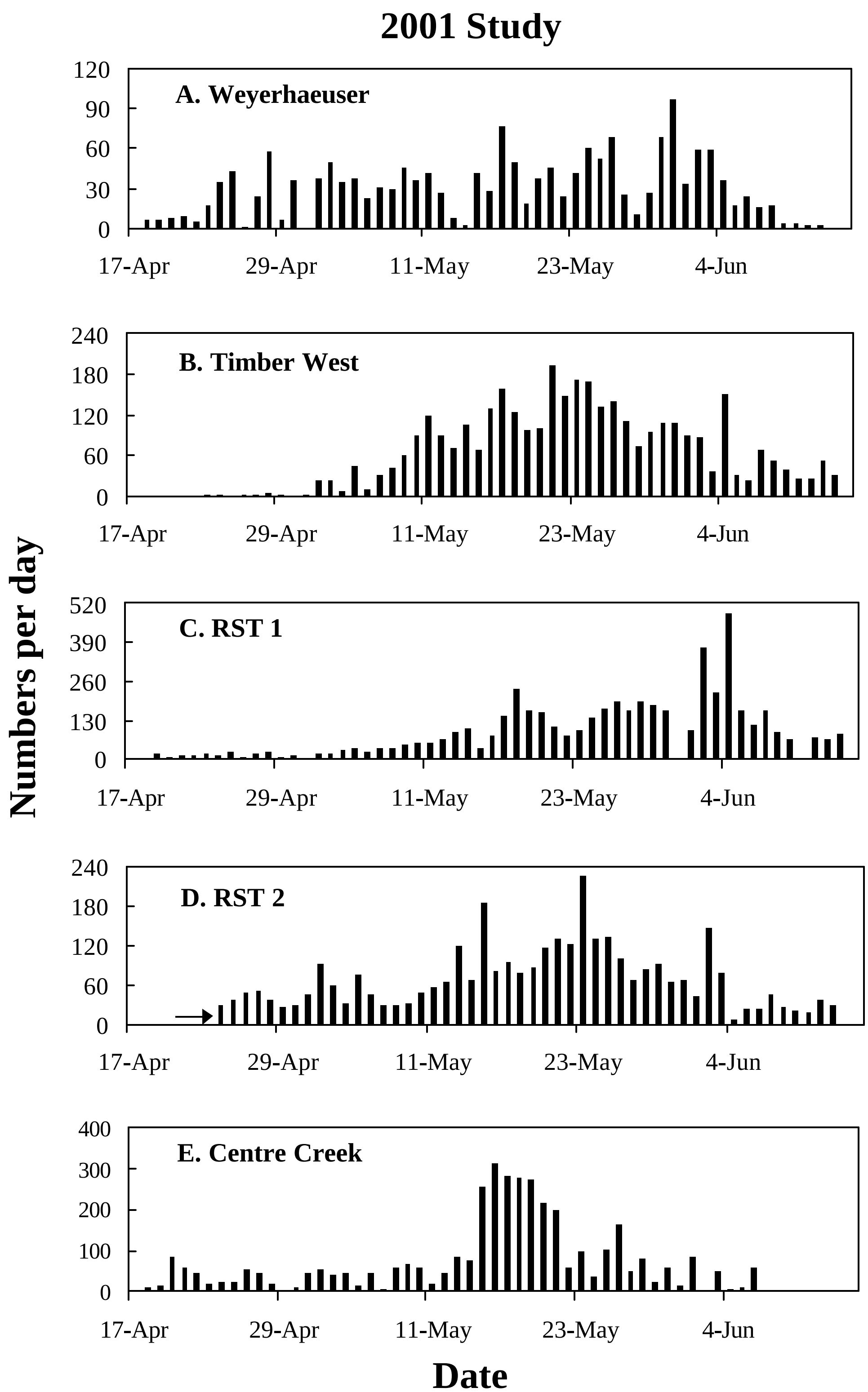


Figure 6. Daily catches of coho smolts at the Weyerhaeuser and Timber West side-channel sites, in Centre Creek and at two rotary screw traps (RST 1 and RST 2) in the Englishman River during 2001 (where present, arrows indicate beginning or end dates for downstream trapping).

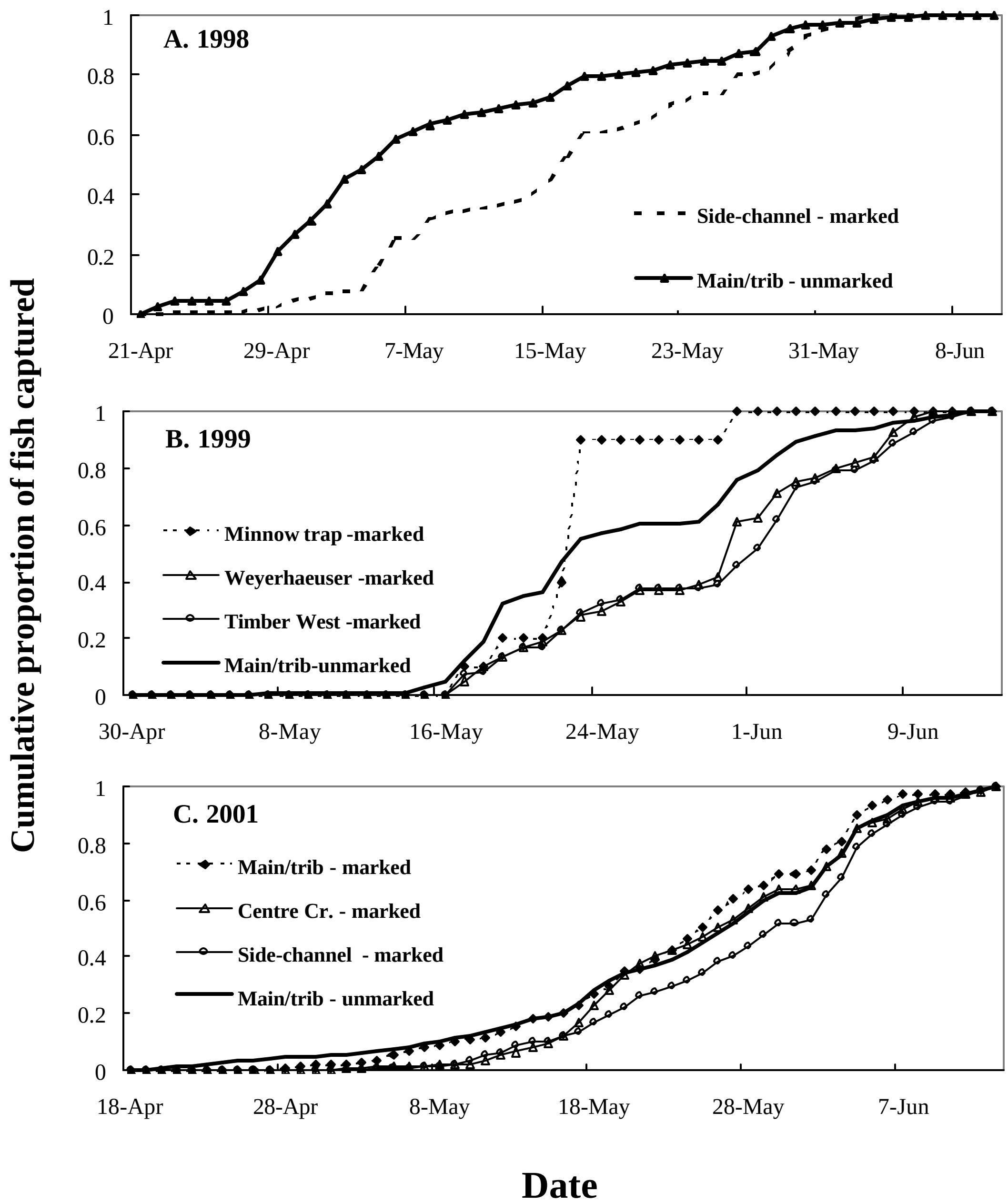


Figure 7. Cumulative daily proportions of marked coho smolts from various release sites in the Englishman River, and unmarked smolts from the mainstem/tributary area captured at the downstream recovery site (RST 1) in the Englishman River in 1998, 1999 and 2001.

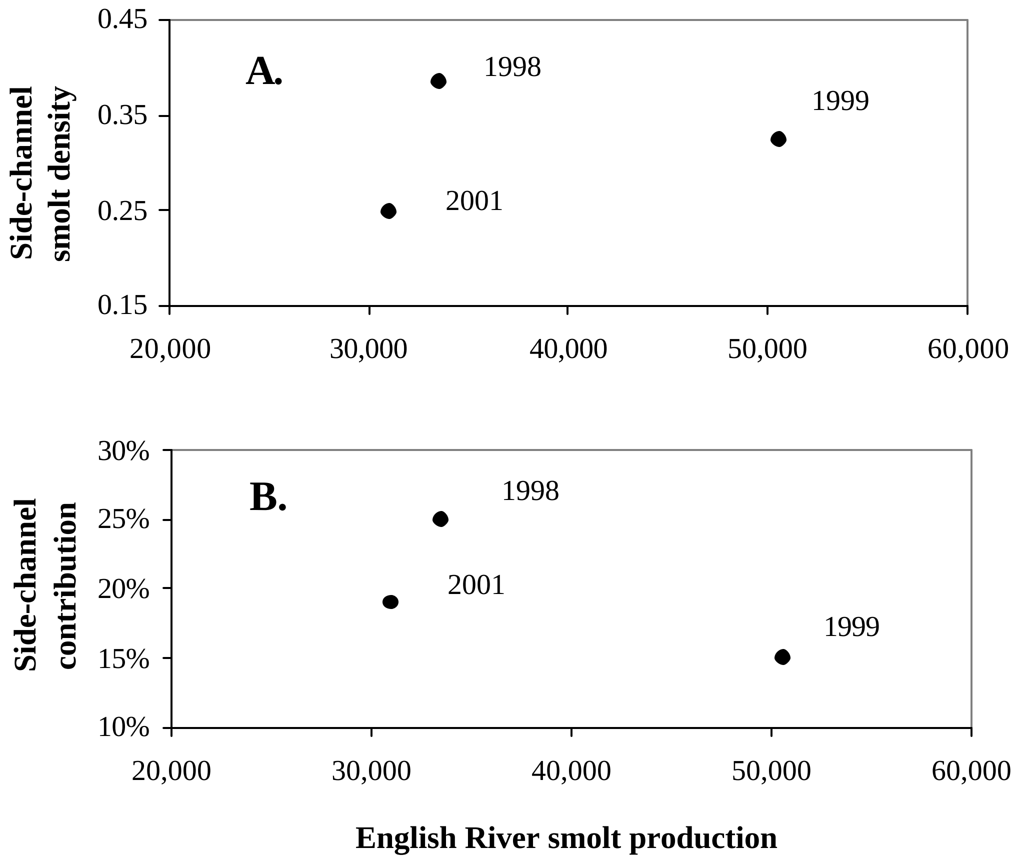
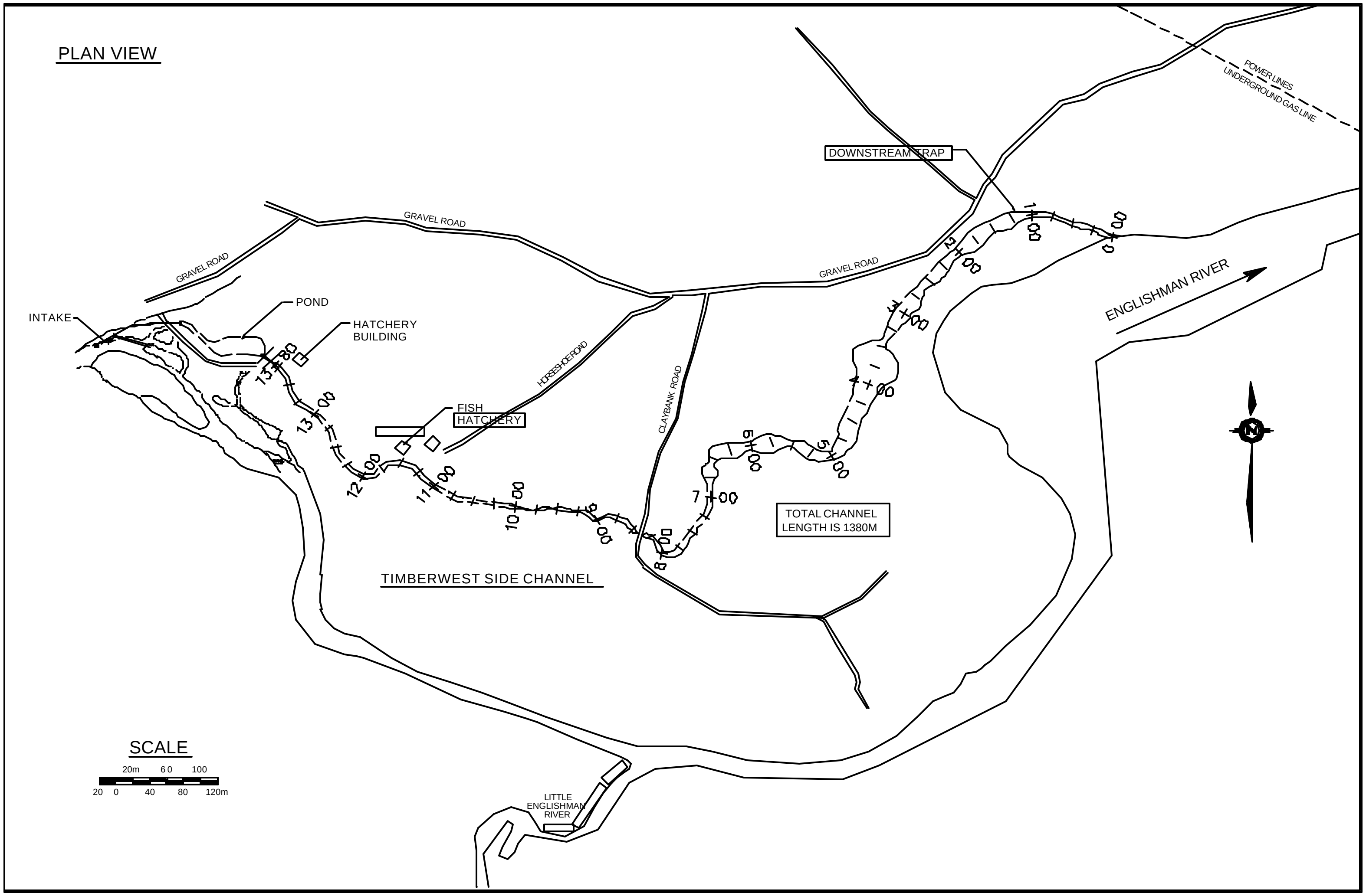
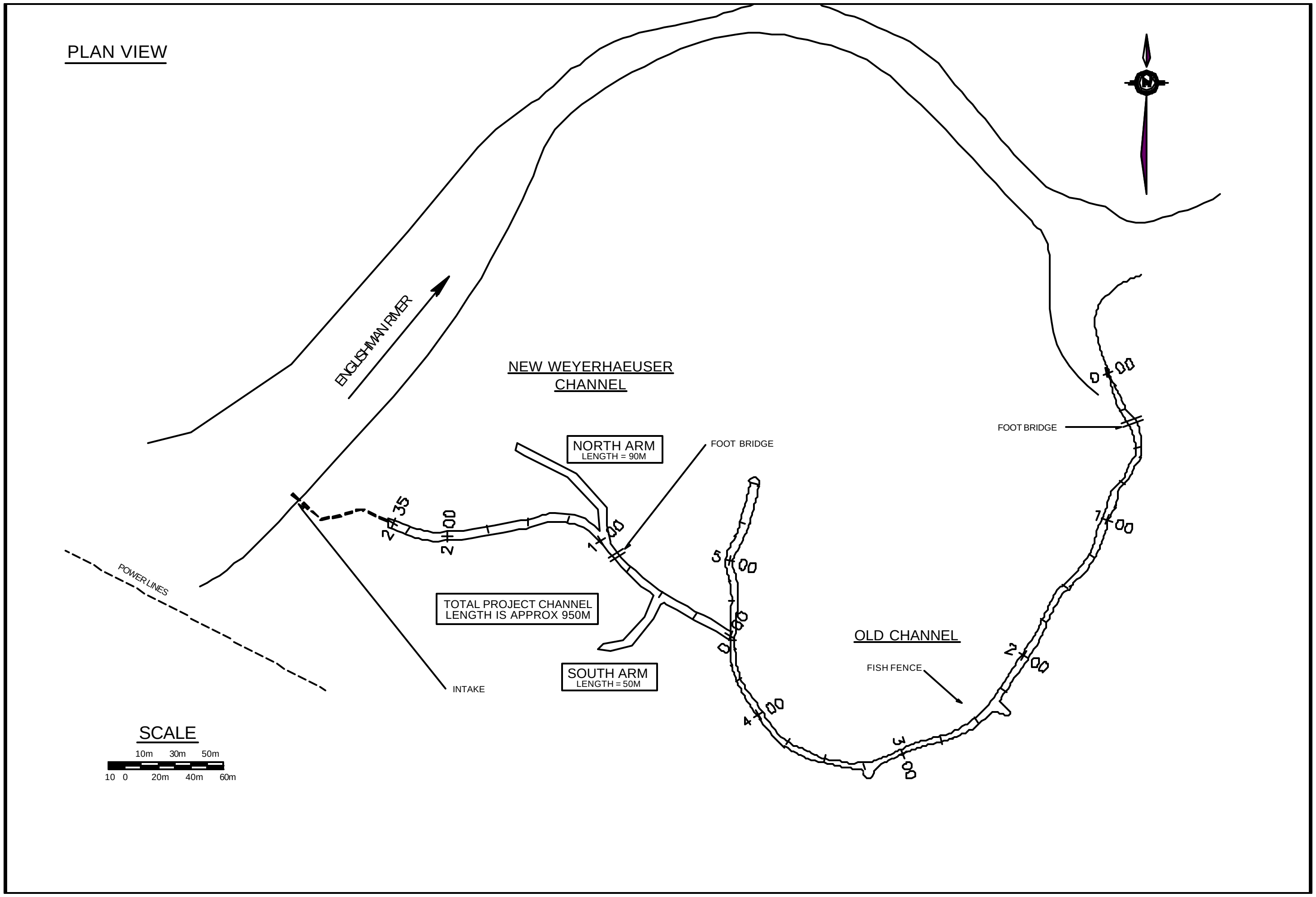


Figure 8. Mean smolt density (smolts?m^2) in side-channels (A), and the percentage of total smolt production contributed by side-channels (B) at different levels of overall smolt abundance in the Englishman River during 1998, 1999 and 2001.

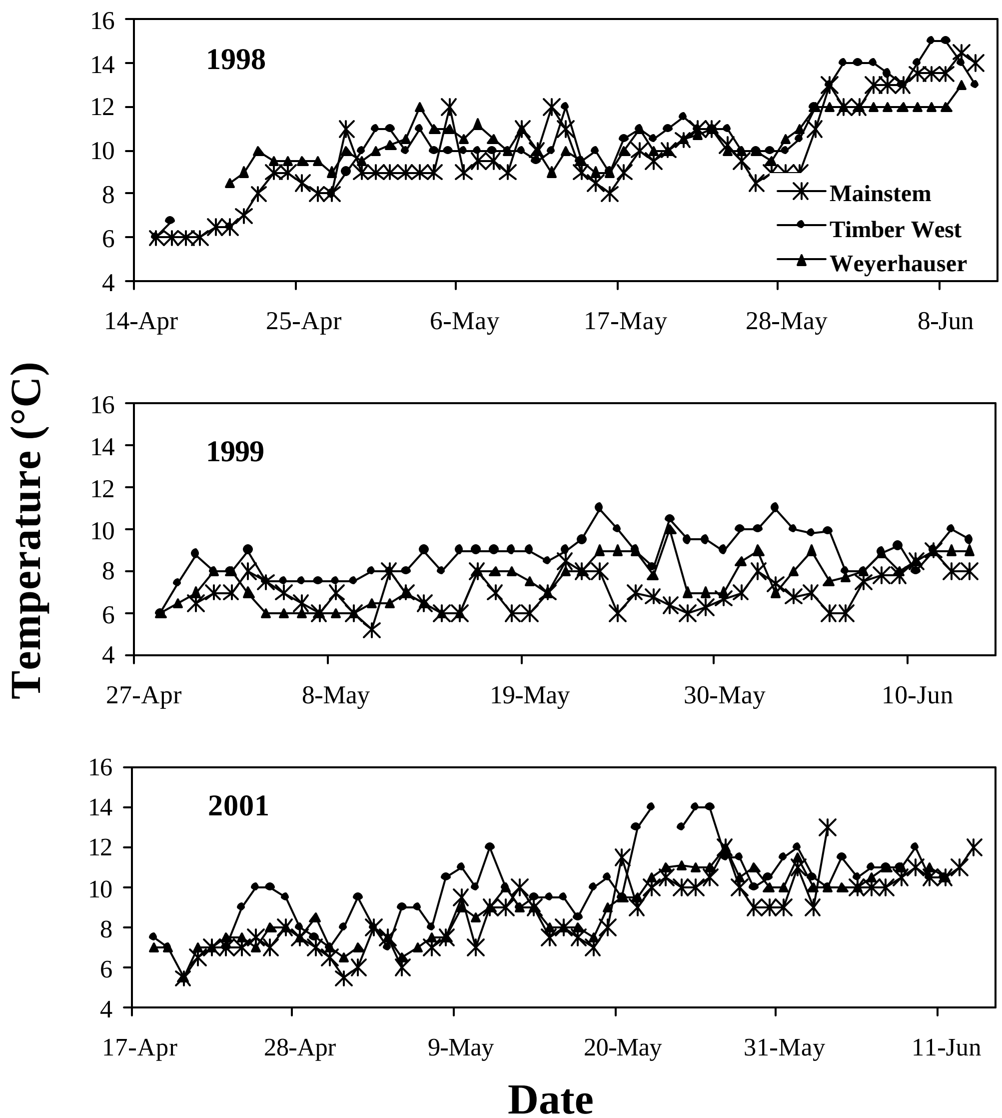
APPENDICES



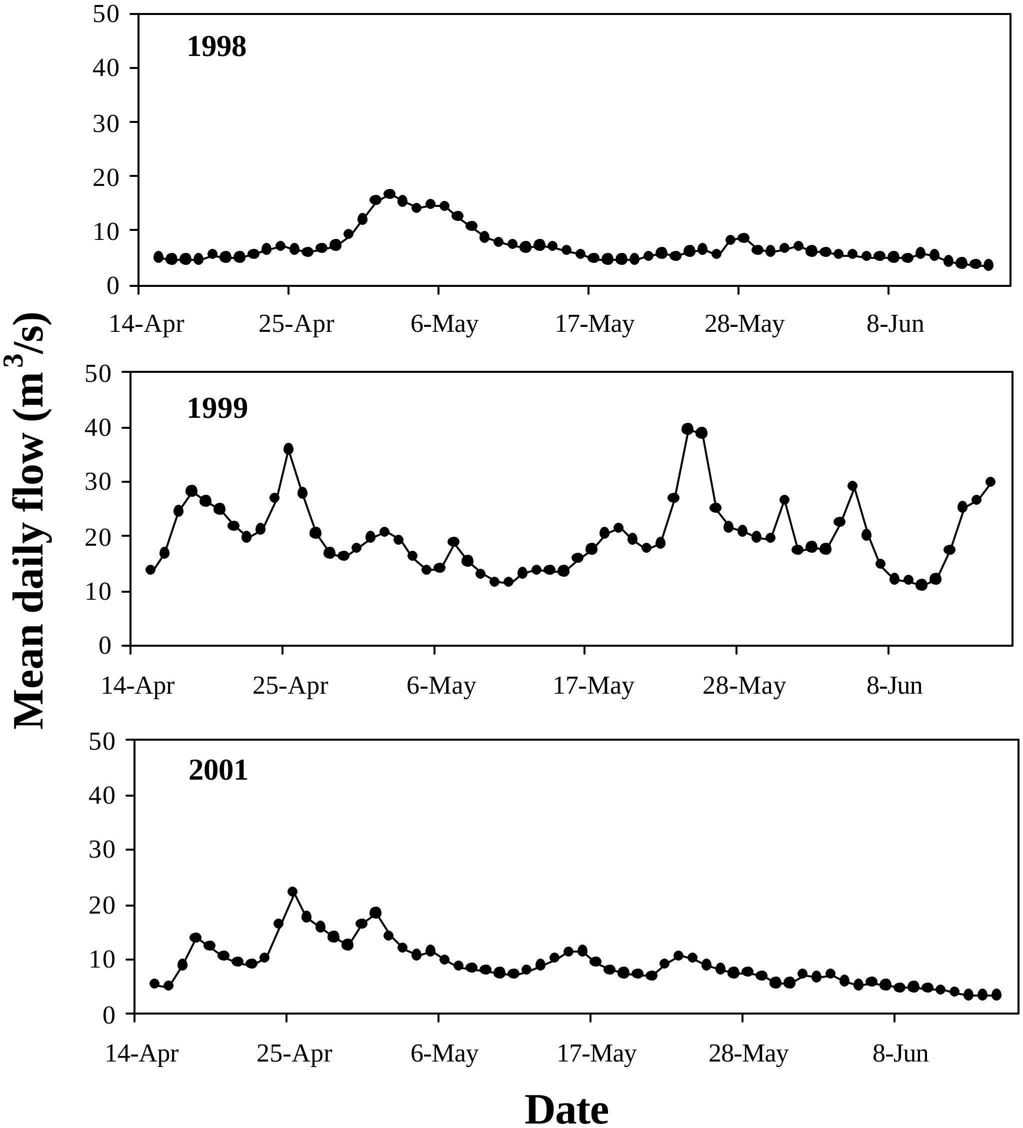
Appendix 1. Drawing of Timber West Channel.



Appendix 2. Drawing of Weyerhaeuser Channel.



Appendix 3. Water temperatures for the Timber West and Weyerhaeuser (M&B) side-channels and the Englishman River, recorded during the study period in 1998, 1999 and 2001.



Appendix 4. Mean daily flows in the Englishman River during the study period in 1998, 1999 and 2001 (WSC Station 08HB002).